T. M. REYNOLDS

EXPERIMENTAL DETERMINATION OF THE RESISTANCE OF SINGLE TRUCK ELECTRIC RAILWAY CARS ON TANGENT TRACKS

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EXPERIMENTAL DETERMINATION OF THE RESISTANCE OF SINGLE TRUCK ELECTRIC RAILWAY CARS ON TANGENT TRACKS

by

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The object of this experimental thesis is:

1. The development of the necessary apparatus for the determination of the velocity, at successive equal intervals, of a single truck electric railway car while drifting down a known grade.

2. A determination of the resistance of single truck electric railway cars under ordinary conditions.

Analysis of Car Resistance

The velocity of a car being known at successive station points along a track whose grade is also known, the forces acting upon the car may be calculated by equaling force through space to difference in velocity head into unit weight. This let F equal the summation of all forces acting on a car. Then F would consist of the algebraic summation of grade resistance G, the curve resistance C, and the resistance of straight level track f. In the term G a minus sign indicates an ascending grade and a plus sign a descending grade. The terms f and C are essentially negative.

$$F = \pm G - C - f \text{ - - - - - - - - - - - - - - - - (a)}$$

Summation of forces F, times the distance equals the unit weight times the difference in velocity heads. Let d equal length of space interval, here taken at twenty feet, and let the unit weight be one ton or 2,000 lbs., so that the several unit forces above become pounds per ton.

Then Fd equals the work done through space by the force F acting through the space or distance d along the track.

In the case of a level track; C = 0 and $\pm G = 0$, and substituting in equation (a) we have

$$F = -f$$

$$Fd = -fd = 2000\ (h_2 - h_1) \text{ - - - - - - - - - - (b)}$$

The values of h_2 and h_1, the velocity heads for the initial and final velocities, V_2 and V_1, are obtained from the formula $V^2 = Vgh$ or $h = {}^{V^2}/_{Vg}$

Substituting twenty feet for d in (b)

$F = - f = 100 (h_2 - h_1)$ - - - - - - - - - - - -(c)

In the case of a grade and straight track, C is 0 in equation (a)

$F = \pm G - f$

but $Fd = d (\pm G - f) = 2000 (h_2 - h_1)$

Let d = 20 feet and dividing through by 20,

$\pm G - f = 100 (h_2 - h_1)$

Transposing, $f = \pm G - 100 (h_2 - h_1)$ - - - (d)

in which f is the car resistance in pounds per ton on straight level track. G is the grade resistance in pounds per ton and $(h_2 - h_1)$ is the difference in velocity heads at the two ends of the 20 foot space interval considered.

As the velocity of the car must be known at successive points before the velocity heights can be computed, the accurate determination of these velocities is essential to the solution of the problem.

The following described method and apparatus have been devised for the purpose of determining the velocity of a car at equal space intervals, while the only forces acting upon the car are f and $\pm$ G.

In the actual field tests of this thesis the observations were taken on a stretch of heavy down grade track growing large positive (+) values for the gravity force G, the car being allowed to drift from a state of rest down the hill over the successive equal space intervals adopted for the purpose of determining velocities with exactness.

Location of Tests.

The tests described in this thesis were conducted on the Wingra Park - Fair Oaks line of the Southern Wisconsin Railway Company, in the city of Madison. The point of observation was on Regent Street near Ely Street. Levels were taken on the top of rail and the stations were marked by making an indentation on the rail with a cold chisel. The ties are exposed and rest in crushed stone ballast which was in a poor condition when the tests were made. The rail is a 60 pound A. S. C. E. section and is badly worn. (See Plate 4). The tests here recorded were made in January 1912 when the roadbed was frozen solid. The attached kodak pictures were taken on the day the tests were made. (Plates 4 and 5). The cars were allowed to descend without brakes or power; that is, the force of gravity, acting alone, was the accelerating force.

Method.

The cars were brought to a standstill at distances varying from ten down to one foot from station zero at the top of the grade. Then the motorman allowed his car to drift by releasing the brakes and not using the motors. The car was allowed to drift freely over a distance of 180 feet. Twenty-foot stations were established and were marked on the rail so that they would be of a permanent nature. Opposite each twenty-foot point a track trigger (See Plates 4, 5 and 6) was so placed that the flange of the wheel would come in contact with it and thus close an electric circuit which communicated with a tuning fork chronograph (Plates 1 and 2). The average speed for the successive twenty-foot intervals was thus accurately obtained. These averages being known, the speed distance curve was plotted and the speed at any point determined from it. In tests one to fifteen, inclusive, the distance from station zero to the wheel was about ten feet, thus giving the car an initial velocity. In tests sixteen to twenty-four, inclusive, the distance from a rest or standstill varied from five to two feet.

Apparatus.

The tuning fork chronograph (Plates 1 and 2) consists of a tuning fork, V, mounted on a rigid support, E, and operated by an electromagnet (A). The source of E. M. F. was two No. 6 dry cells (Plates 1 and 2). The instrument was designed in

1906 - 07 by E. L. H. Lorenz, formerly chief mechanician of the College of Engineering, under the direction of Professor W. D. Pence of the Department of Railroad Engineering. In the same box with the tuning fork is mounted a set of clockworks (Plates 1 and 2) which furnish the motive power to unwind a roll of metallic recording paper, V, upon which autographic records (Plate 8) of the tuning fork vibrations and the trigger constants are registered. The accompanying photographs and key give a good description of the chronograph. The paper is unwound at the rate of about 15 feet per minute which gives a good record of the vibrations so that if necessary the time could be obtained to the nearest one-quarter of a vibration or one two-hundredths of a second.

The track trigger (Plates 4, 5, and 6) consists of a piece of brass tubing, a, about eight inches long mounted on two supports, b. A piston, h, made out of a smaller piece of tubing and about four inches long is allowed to slide in the outer piece. The sliding motion is produced by a spiral spring, c, under compression. One support has a lever, d, mounted on it, which is engaged by the flange of the wheel. This lever has a notch cut in it on the inside end which hooks onto a catch, f, riveted to the piston, h. To allow the catch to project through the outer casing a rectangular slit has been cut in it. At the beginning

of each test, the piston was drawn forward compressing the spring, c, and the lever, d, hooked on to the catch, f. Then as the flange hit the lever, d, the piston would be forced back about three and one-half inches by the compressed spring, c. While the piston is sliding back it forces up a steel conical shaped button bringing together the strips of copper, g, (Plate 6) which close the track circuit leading to the chronograph.

The duration of contact in the track circuit was not instantaneous because it was found in former trials (See thesis of Pflans and Schwada, 1911) with instantaneous contacts that the attractive force of the electromagnet, B, (Plate 2) did not build up fast enough to secure a record. In the device as shown on Plates 4, 5, and 6 the length oc contact varies from one-tenth to one twenty-fifth of a second. It is readily seen from the sample records (Plate 8) that it takes at least one one-hundredth of a second for the magnet to "build up" or move properly. This was the period of motion of the armature in response to the magnetic pull. In a warm room (70° F.) the triggers worked very fast, but at a temperature of 25° F the piston moved very sluggishly and at a temperature of - 4° F, several refused to slide all the way back, thus keeping the track circuit closed and rendering the test worthless.

The triggers were nailed to 2 by 4 inch supports (Plate 4) which were in turn spiked to the ties. This arrangement brought

the top of the lever, d, about one-eight inch above the top of the rail. The outer end of the lever was placed three-eights of an inch from the rail, thus protecting the lever in its lowest position from a blow from the flange of the succeeding wheels.

The source of electricity for the track circuit consisted of five No. 8 dry cells. Two No. 6 cells were sufficient for the operation of the tuning fork. No. 14 rubber insulated copper wire was used and the current was sent into the distribution system at the center. A reserve battery of five No. 8 and two No. 6 cells were kept on hand.

The accompanying sketches, photographs and keys give a clear idea of the apparatus and its arrangement.

Calibration.

The tuning fork chronograph was calibrated in the Physics Laboratory. A pendulum beating records was connected to a telegraph relag, which in turn was connected to the magnet in the track or trigger circuit. One run of ten seconds was made.

Results of Calibration Tests.

	100.0	half	vibrations	per	second
	100.0	"	"	"	"
	102.0	"	"	"	"
	101.0	"	"	"	"
	101.5	"	"	"	"
	101.5	"	"	"	"
	101.0	"	"	"	"
	102.5	"	"	"	"
	99.0	"	"	"	"
Total	908.5	"	"	"	"

100.95 = Average half vibrations per second.

50.475 = Average whole vibrations per second.

Sample Computations.

The first step is to count the number of fork vibrations on the ribbon record between two 20 - foot station points. The velocity in feet per second is then obtained in the following manner.

Average number of vibrations per second = 50.475

Let X = number of vibrations per 20 feet.

$\frac{X}{20}$ = number of vibrations per one foot

$$\frac{50.475 \times 20}{X} = \frac{1009.50}{X} = \text{speed in feet per second}$$

This velocity is then squared and the difference of the squares taken. Then $(h_2 - h_1)$ is obtained by dividing $(V_2 - V_1)$ by 2g or 64.32.

Then from formula (d) page 3

$$f = G - 100\,(h_2 - h_1)$$

Consider Test No. 12, Car No. 51

Number of vibrations between 0 and 0 + 20 = 89.5

Number of vibrations between 0 + 20 and 0 + 40 = 76.75

$\frac{1009.50}{89.50}$ = 11.280 feet per second.

$\frac{1009.50}{76.75}$ = 13.153 feet per second.

Difference of the squares = 45.79. $45.79 \div 64.32 = 0.712$

$f =$ 84.70 - 71.20 = 13.50 pounds per ton.

Weather Conditions on January 23, 1912

Time	Temperature Degrees F	Velocity of the wind	Prevailing direction of the wind
8:00 A. M.	26	12	N W
9:00 A. M.	25	12	N W
10:00 A. M.	25	8	N
11:00 A. M.	25	9	N W
12:00 M.	25	9	W
1:00 P. M.	25	9	W
2:00 P. M.	25	10	N W
3:00 P. M.	25	9	N W
4:00 P. M.	25	10	N W
5:00 P. M.	23	6	N W

Sun - shining.

These records were furnished by Mr. E. R. Miller, Forecaster of the United States Weather Bureau, at Madison, Wisconsin.

Determination of Grade Effect "G"

Station	Difference in Elevation	Rate of Grade %	G in lbs. per ton
0			
	0.847	4.235	84.70
+20			
	0.882	4.410	88.20
+40			
	0.962	4.810	96.20
+60			
	0.894	4.47	89.40
+80			
	0.920	4.60	92.00
1+00			
	0.961	4.805	96.10
+20			
	0.960	4.800	96.00
+40			
	0.990	4.950	99.50
+60			
	0.995	4.975	96.90
+80			
	0.965	4.845	93.60
2+00			
	0.936	4.680	94.70
+20			
	0.947	4.735	
+40			

When the grade is descending "G" is plus, when ascending "G" is minus.

Key to Sketches and Photographs.

A Electromagnet operating tuning fork.

A Bending posts in circuit A.

B Electromagnet in track circuit operating arm W.

B Bending posts in circuit B.

C Detachable drum upon which paper winds.

D Armature for magnet B.

E Rigid support holding tuning fork.

F Brass core for speed recording paper.

G Electromagnet used in starting clockwork.

H Armature of G.

I Lever used in starting clockwork by hand.

J Lever lifting riding plate for paper up to pencil points.

K Switch for circuits A and G.

L Aluminum plate upon which brass pencil points bear.

N Screw switch in tuning fork circuit.

P Pivot reversing of motion of D.

P Brass pencil points on arm W in circuit B.

P Brass pencil point on tuning fork

R Rollers facilitating movement of paper under pencil points.

S Spring controlling pressure of P on paper.

S Spring controlling magnitude of deviation of p.

S Spring controlling speed of F.

T Thin strip of spring steel connecting armature D with arm W holding P .

U Counterweight spring contact.

U Counterweight pencil

V Metallic surfaced recording paper.

W Arm holding brass pencil point in circuit B.

X Handle for winding clockwork.

Y Tuning fork.

a Brass tubing.

b Bronze supports.

c Spiral spring.

d Lever.

f Catch soldered to piston h.

g Copper strips

g Binding posts in track circuit.

h Brass piston.

k Conical shape needle.

m Wood fibre for insulation purposes.

n 2 x 4 supports nailed to ties.

Test No. 24 Car No. 50

Time - 4:15 p. m.

Station	Vel. ft/sec	v^2	$v_1^2 - v_2^2$	$h_1 - h_2$	f in #/ton
0					
	6.25	39.06			
+ 20			65.24	1.0143	16.73
	10.20	104.30			
+ 40			27.60	0.4291	45.29
	11.485	131.90			
+ 60			44.50	0.6919	27.01
	13.282	176.40			
+ 80			40.56	0.6306	26.34
	14.73	216.96			
1 + 00			48.47	0.7527	16.73
	16.283	265.38			
+ 20			48.27	0.7506	21.04
	17.71	313.65			
+ 40			43.05	0.6694	29.06
	18.868	356.70			
+ 60			46.90	0.7293	26.07
	20.09	403.60			
1 + 80					

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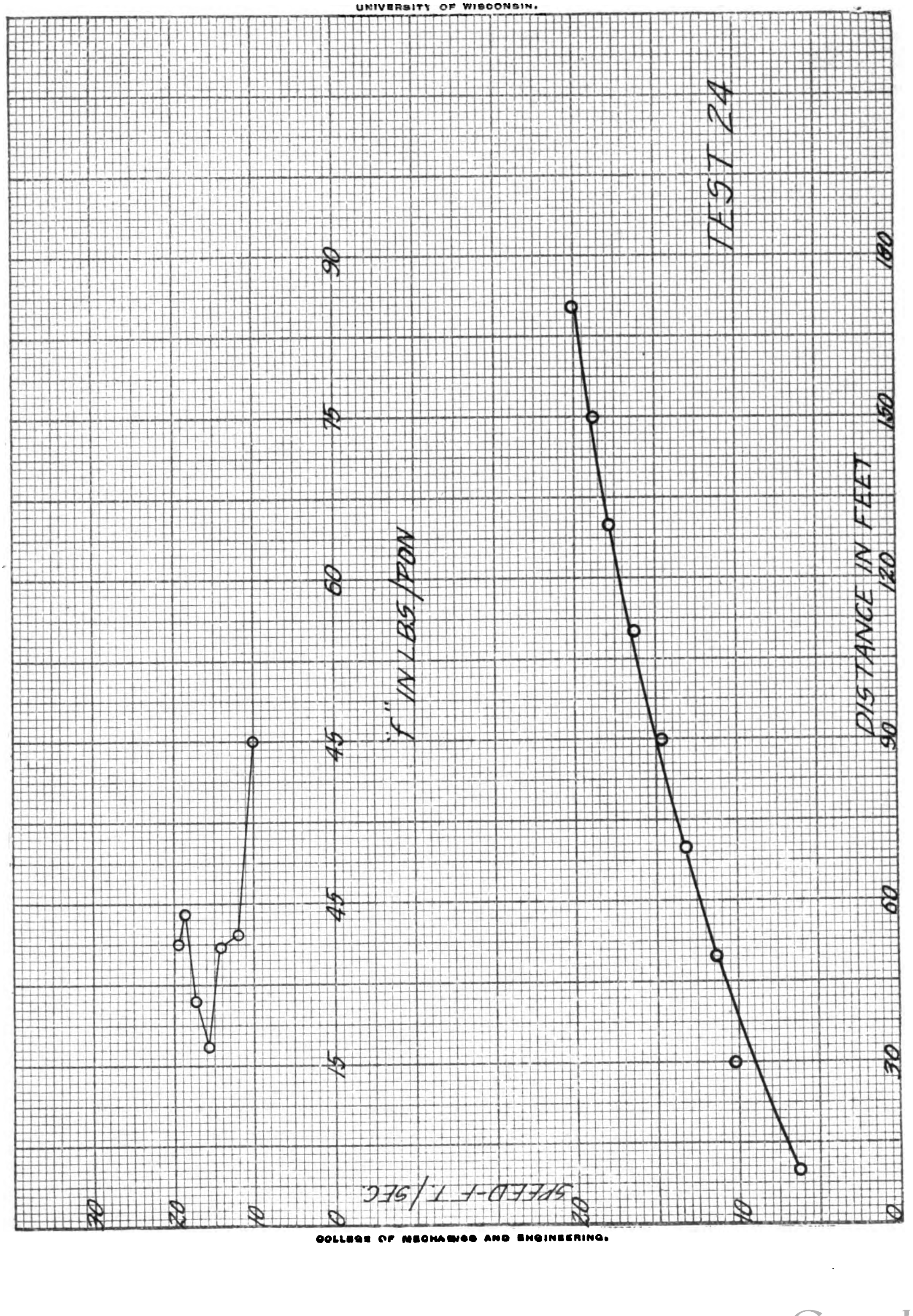

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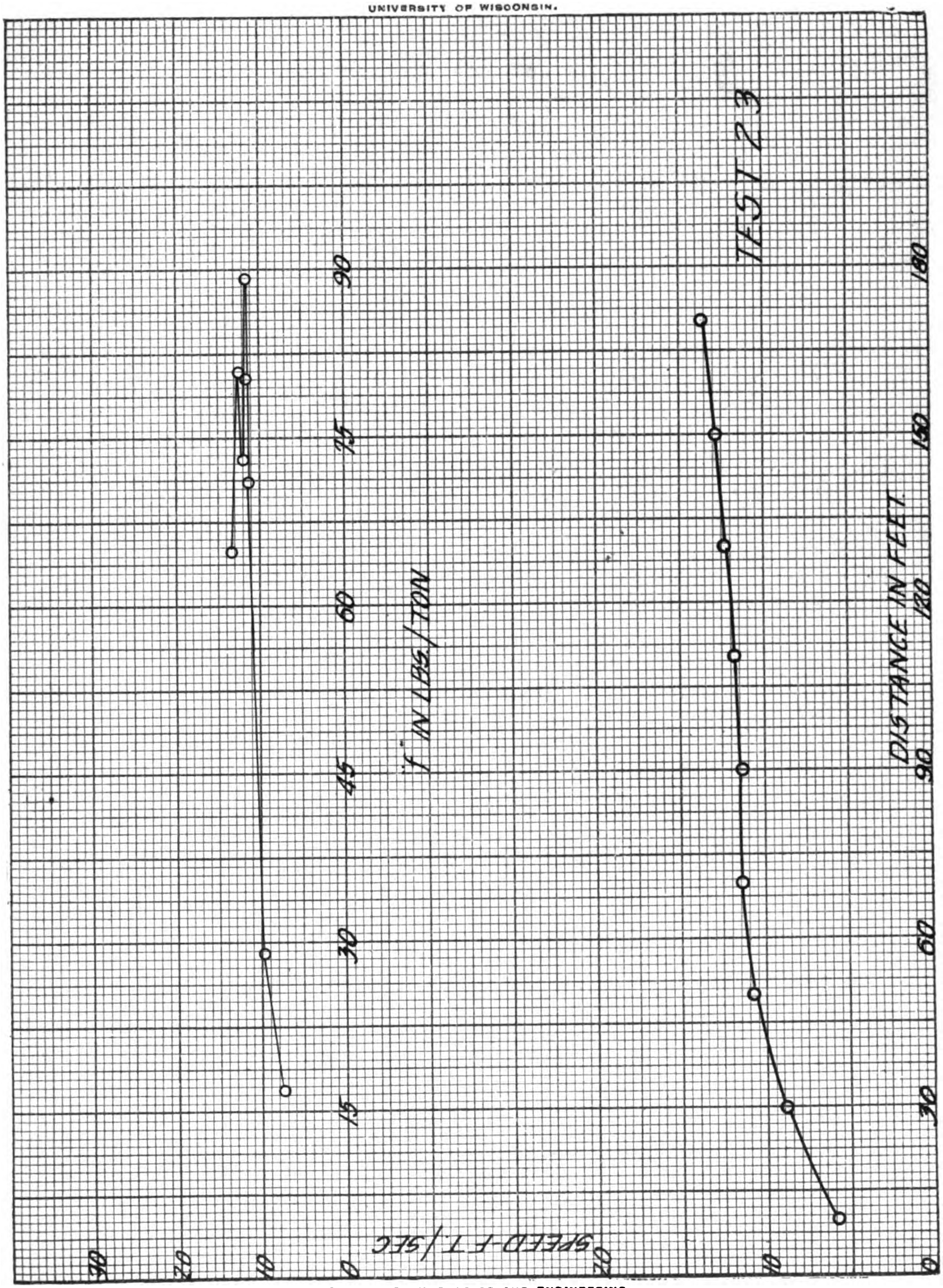
Test No. 23 Car No. 52

Time - 4:30 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	5.83	33.99			
+20			43.62	0.6783	16.87
	8.81	77.61			
+40			37.95	0.590	29.20
	10.75	115.56			
+60			16.34	0.2541	70.79
	11.485	131.90			
+80			0	0	89.40
	11.485	131.90			
1 +00			7.58	0.1178	80.22
	11.81	139.48			
+20			14.92	0.232	72.9
	12.385	154.40			
+40			9.70	0.1508	80.92
	12.81	164.10			
+60			22.00	0.342	64.8
	13.642	186.10			
1 +80					

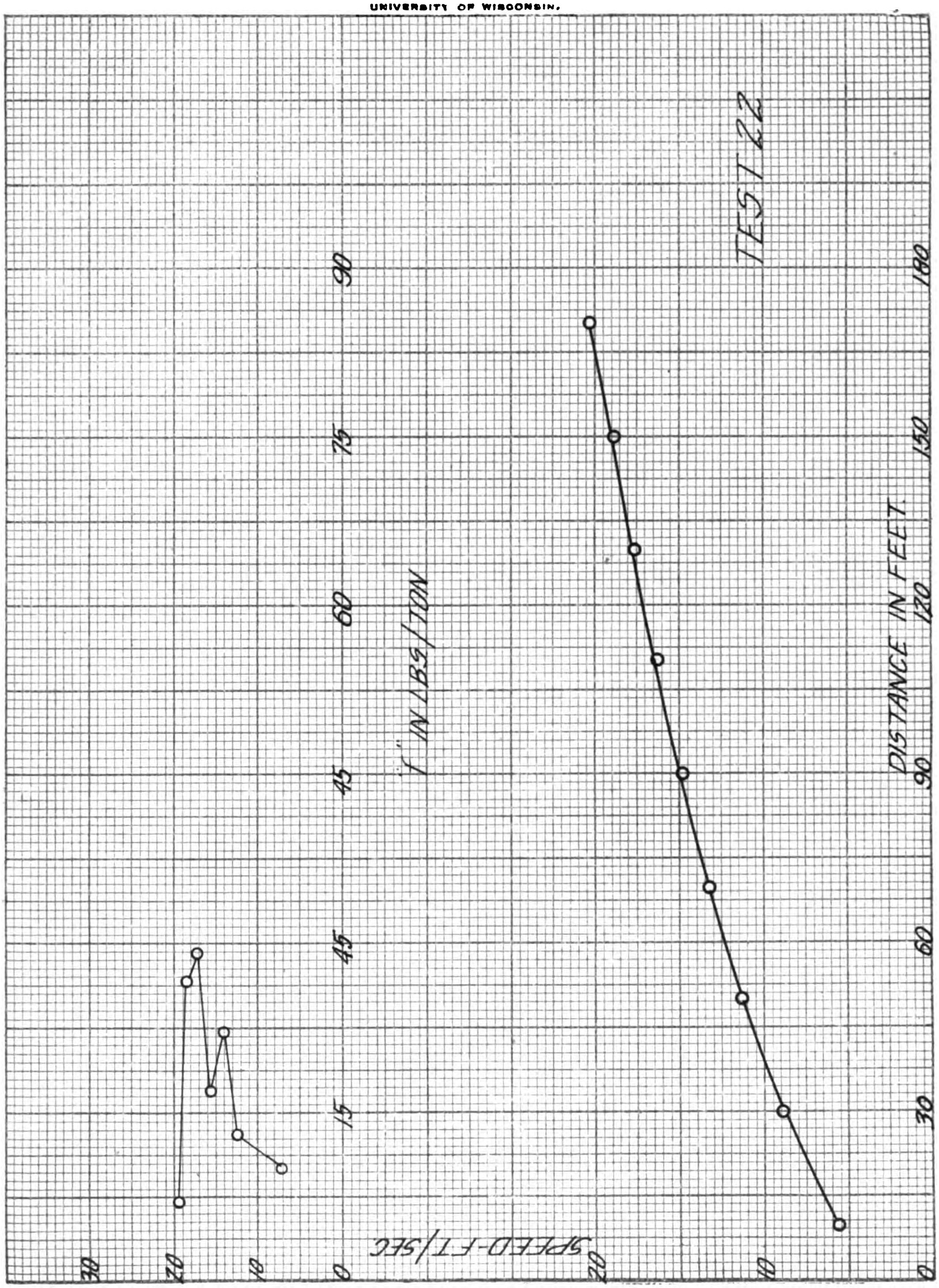
Note:- Brakes were set.


TEST 23
"f" IN LBS/TON
15
30
45
60
75
90
DISTANCE IN FEET
30
60
90
120
150
180
SPEED-FT./SEC
0
10
20
30

Test No. 22 Car No. 46

Time - 4:00 p.m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	5.65	31.92			
+20			47.895	0.7447	10.23
	8.934	79.815			
+40			47.415	0.7372	14.48
	11.28	127.23			
+60			46.90	0.7293	13.27
	13.196	174.13			
+80			42.83	0.6660	22.80
	14.73	216.96			
1 + 00			48.42	0.7529	16.71
	16.283	265.38			
+ 20			42.91	0.6672	79.38
	17.558	308.29			
+40			44.49	0.6918	26.82
	18.78	352.70			
+60			59.00	0.9174	7.26
	20.29	411.70			
1 + 80					


TEST 22
DISTANCE IN FEET.
F IN LBS/TON
SPEED-FT/SEC
0
30
60
90
120
150
180
15
45
75
10
20
30

Test No. 21 Car No. 45

Time - 3:40 p. m.

Station	vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	5.22	27.25			
+20			35.53	0.5525	79.45
	7.93	62.88			
+40			35.53	0.5525	32.95
	9.82	98.41			
+60			36.14	0.5620	40.00
	11.60	134.55			
+80			29.55	0.4595	43.45
	12.81	164.10			
1+00			35.27	0.5486	37.14
	14.18	199.37			
+20			41.03	0.638	32.30
	15.505	240.40			
+40			33.40	0.5194	44.06
	16.55	273.80			
+60					
	31.3 - Discarded.				
+80					

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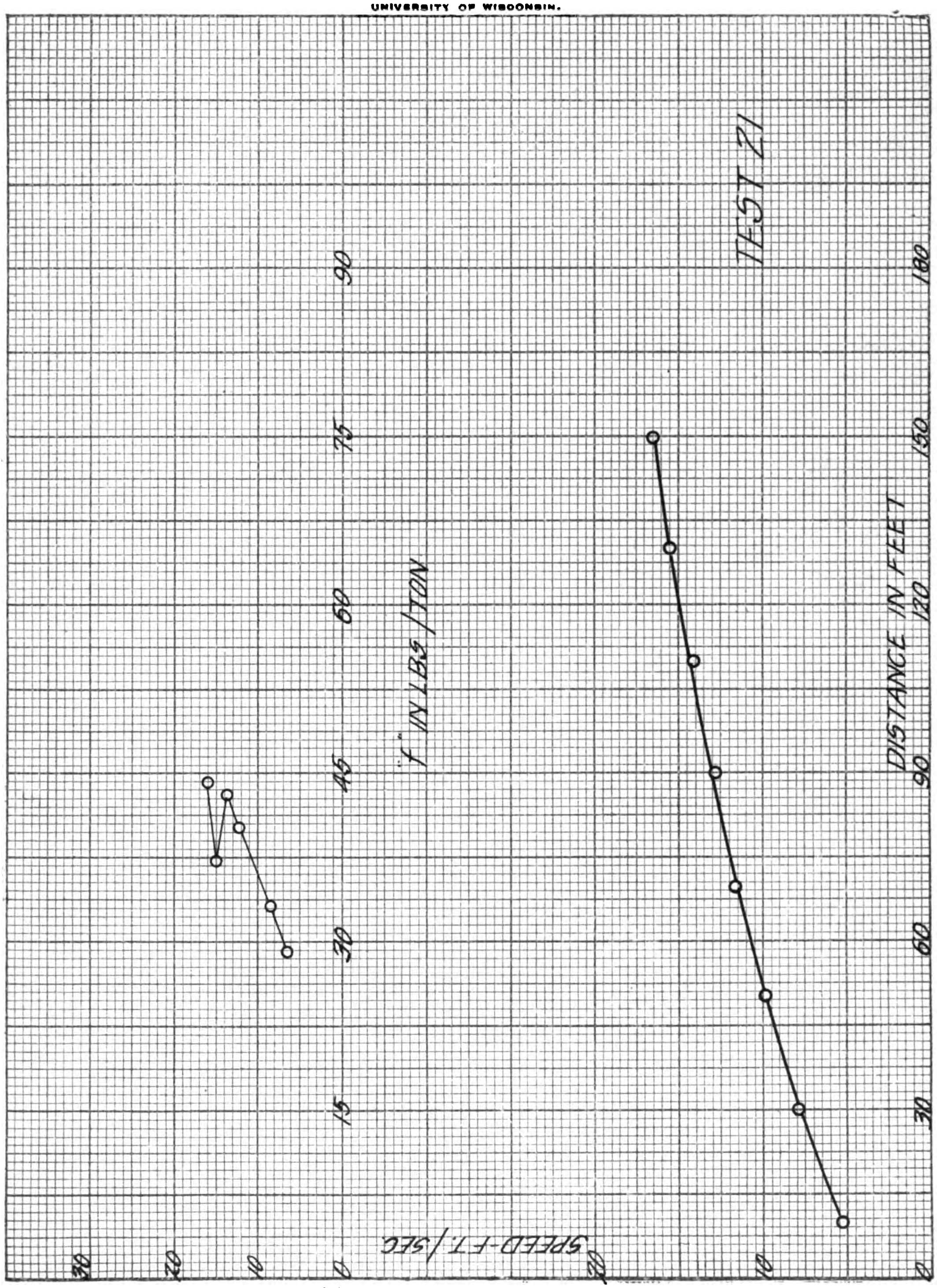

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Test No. 20   Car No. 54

Time - 3:30 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	5.768	33.27			
+20			49.46	0.796	5.10
	9.095	82.73			
+40			45.89	0.7135	16.85
	11.342	128.62			
+60			45.51	0.7076	25.44
	13.196	174.13			
+80			41.47	0.6448	24.92
	14.682	215.60			
1 +00			47.35	0.7362	18.38
	16.217	262.95			
+20			45.34	0.705	25.6
	17.558	308.29			
+40			41.21	0.6408	31.92
	18.694	349.50			
+60			50.10	0.7790	21.10
	19.99	399.60			
1+80					

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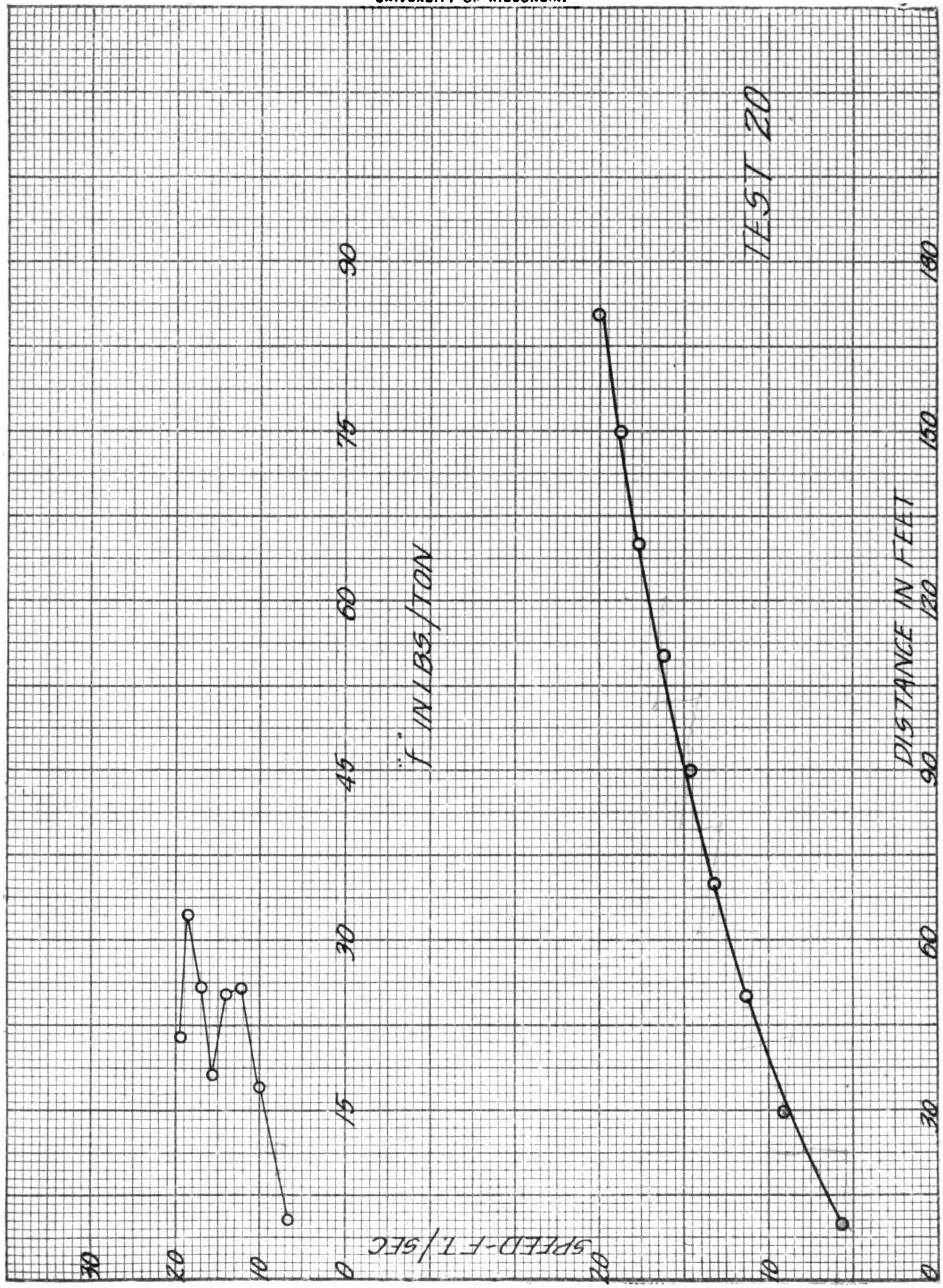

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Test No. 19 Car No. 43

Time - 3:15 p. m.

Station	Vel. ft/ sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	4.171	17.39			
+20			44.33	0.6893	15.77
	7.856	61.72			
+40			43.87	0.6821	19.99
	10.275	105.59			
+60			41.46	0.6446	31.74
	12.126	147.05			
+80			39.05	0.6071	28.69
	13.642	186.10			
1 +00			42.65	0.6631	25.69
	15.123	228.75			
+20			43.77	0.6806	28.04
	16.508	272.52			
+40			35.77	0.5562	40.38
	17.558	308.29			
+60			44.41	0.6905	29.95
	18.78	392.71			
1 +80					

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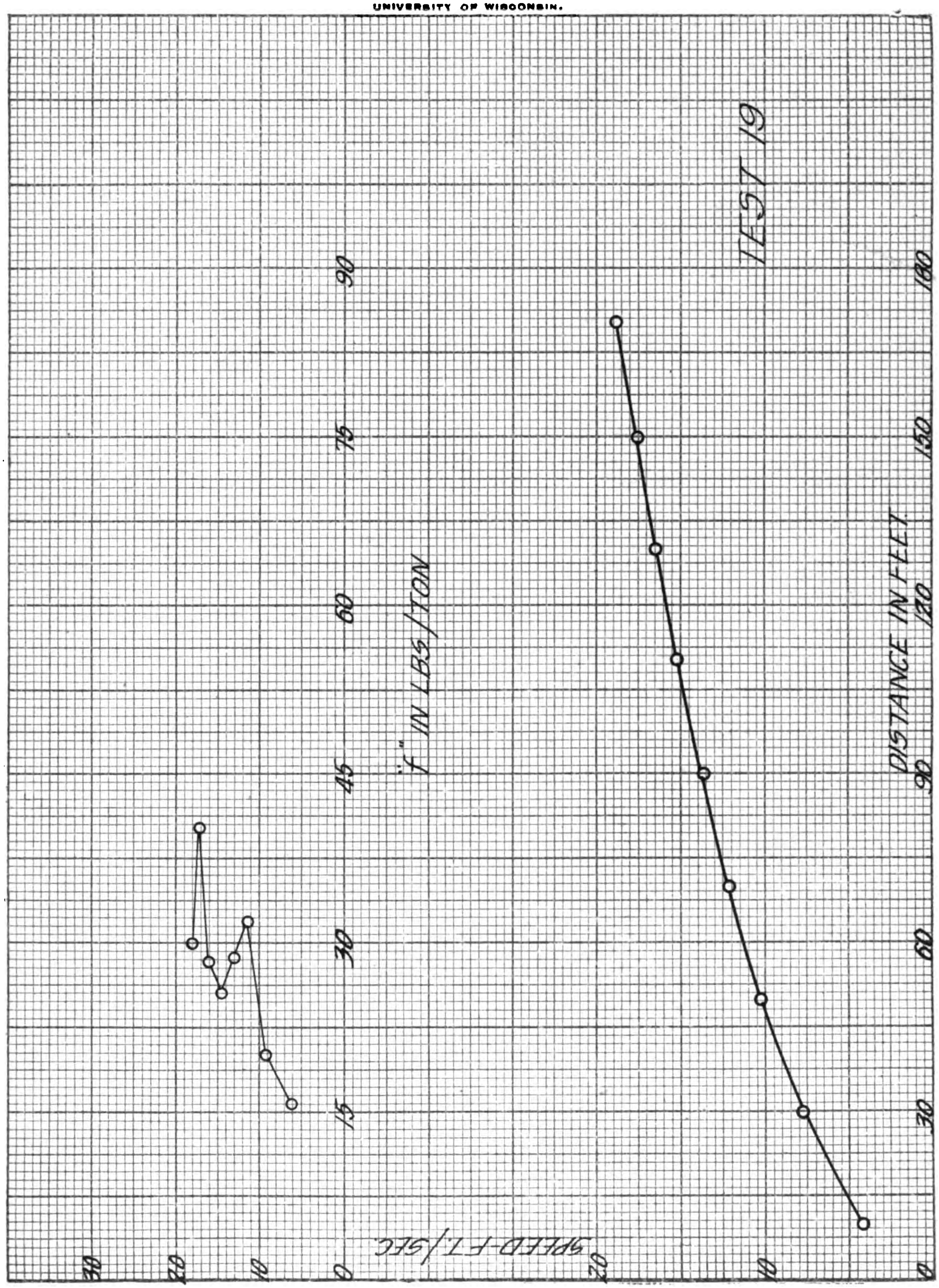

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Test No. 18 Car No. 50

Time 2:50 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in 3/ton
0					
	5.023	25.23			
+20			48.57	0.7751	7.19
	8.591	73.80			
+40			49.29	0.7663	11.57
	11.093	123.09			
+60			40.56	0.724	23.80
	13.025	169.65			
+80			47.31	0.7355	15.95
	14.73	216.96			
1 +00			44.02	0.6842	23.58
	16.153	260.98			
+20			52.67	0.819	14.20
	17.71	313.65			
+40			35.85	0.5574	40.26
	18.694	349.50			
+60			75.00	0.1660	17.60
	20.602	424.50			
1 +80					

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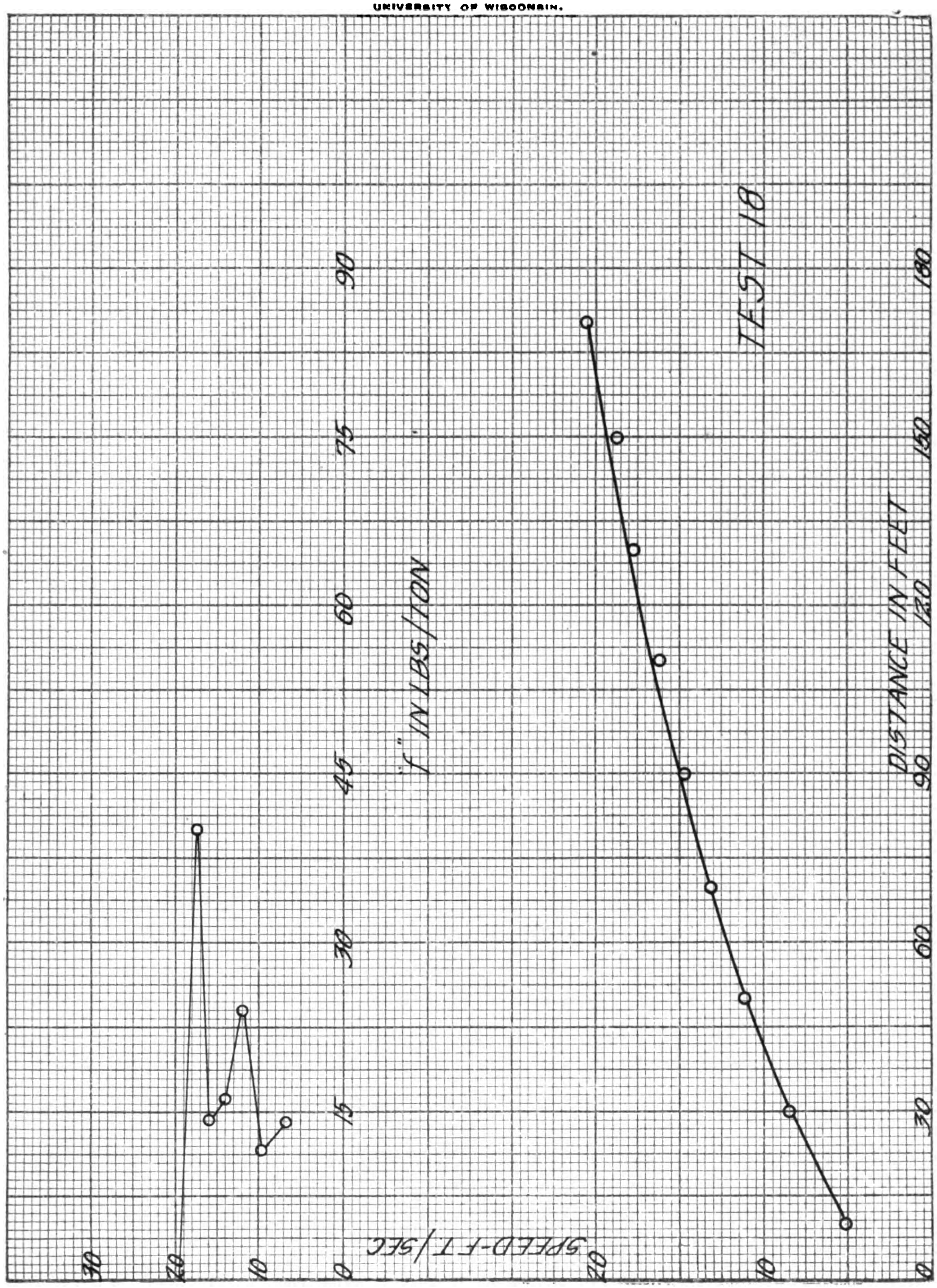

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Test No. 17 Car No. 52

Time - 2:40 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
+20	7.108	50.525			
			82.395	1.281	44.80
+40					
	11.153	132.92			
+60			15.03	0.2337	72.83
	12.163	147.95			
+80			5.45	0.0845	80.95
	12.385	153.40			
1 +00			5.80	0.0901	82.98
	12.613	159.20			
+20			14.93	0.2321	72.89
	13.196	174.13			
+40			4.63	0.0720	88.80
	13.37	178.75			
+60			20.63	0.3208	66.92
	14.12	199.38			
1 +80					

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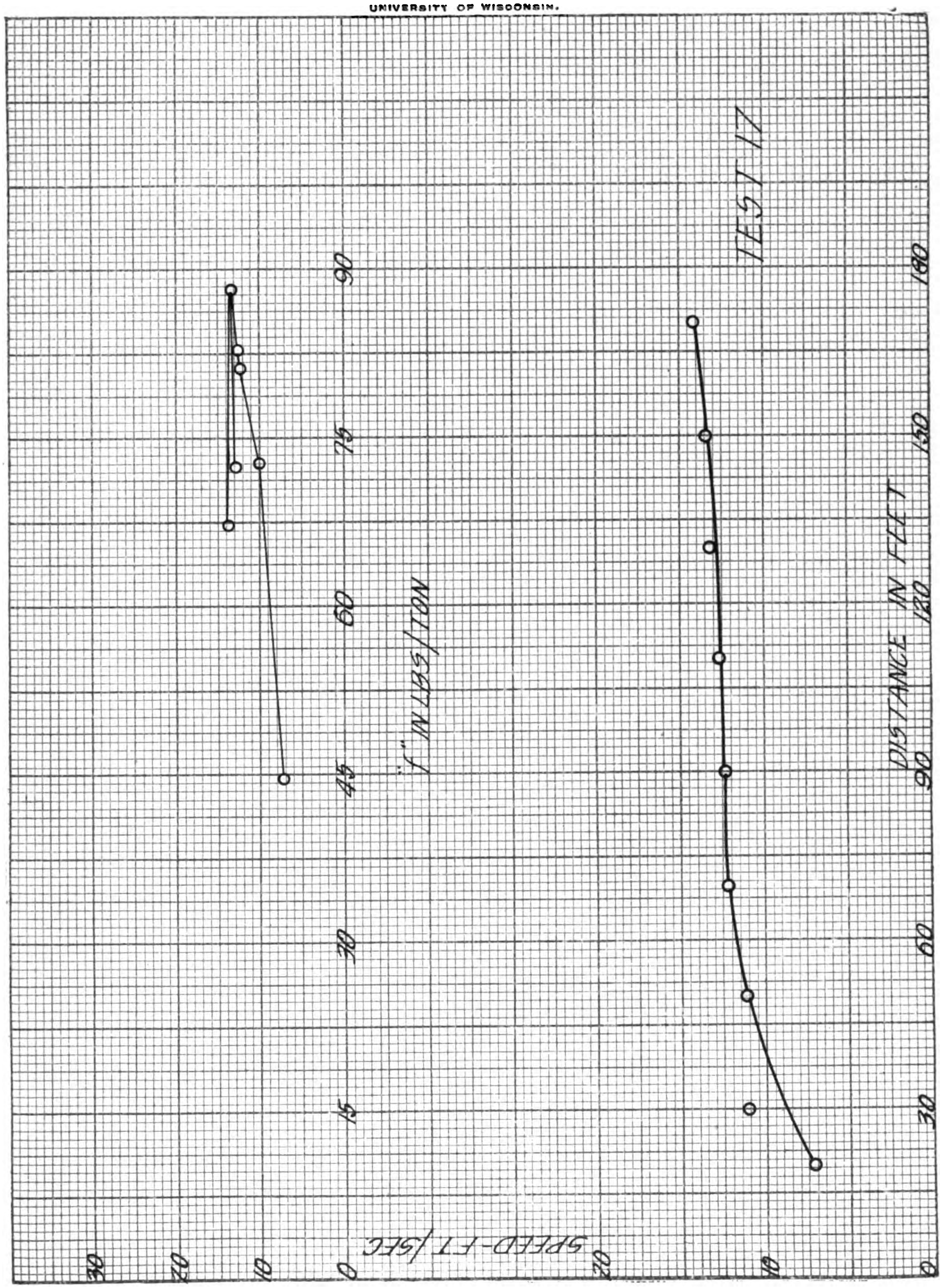

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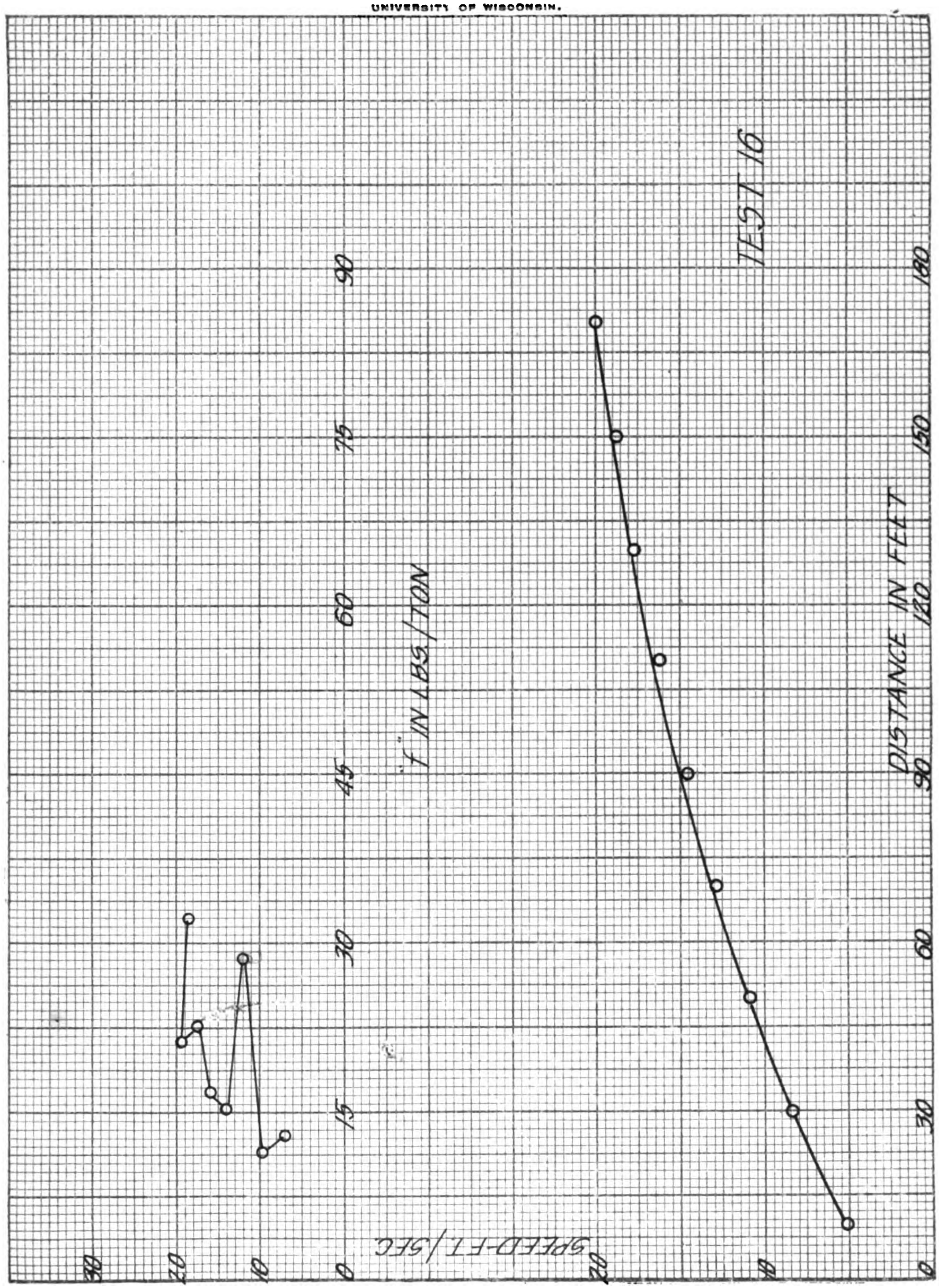
Test No. 16 Car No. 46

Time - 2:25 p. m.

Station	Vel. ft/sec	v^2	$v_1^2 - v_2^2$	$h_2 - h_1$	f in #/ton
0					
	5.01	25.10			
+20			46.26	0.7193	12.77
	8.447	71.36			
+40			49.44	0.7688	11.32
	10.912	120.80			
+60			43.30	0.6733	28.87
	12.81	164.10			
+80			47.70	0.7416	15.24
	14.525	211.80			
1 +00			49.18	0.7647	16.53
	16.153	260.98			
+20			47.31	0.7356	22.54
	17.558	308.29			
+40			41.21	0.6407	31.93
	18.694	349.50			
+60			50.10	0.7789	21.11
	19.99	399.60			
1 +80					

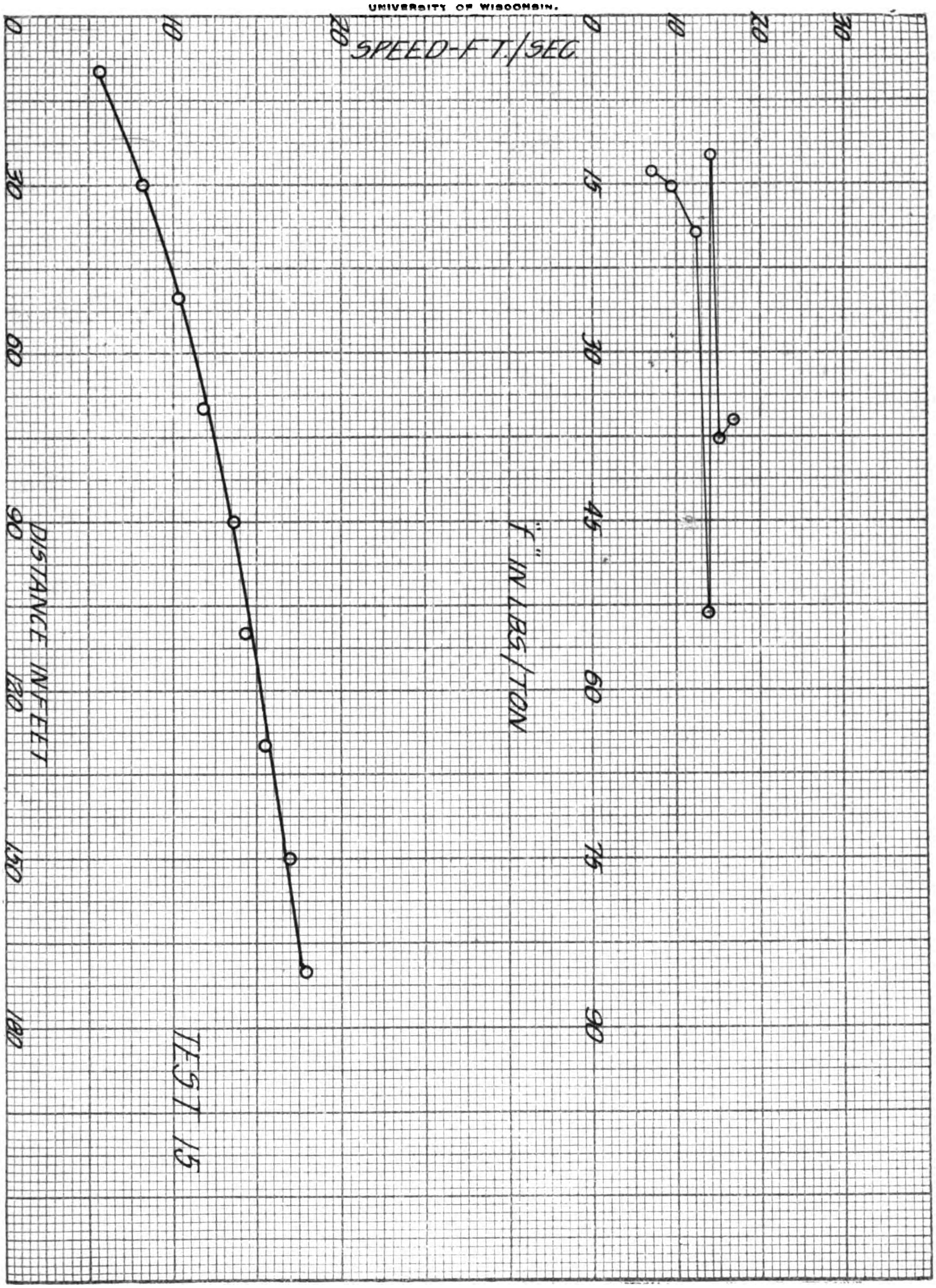

TEST 16
"F" IN LBS/TON
DISTANCE IN FEET
SPEED-FT./SEC.
0
15
30
45
60
75
90
30
60
90
120
150
180
10
20
30

Test No. 15 Car No. 45

Time - 2:05 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in 3/ton
0					
	5.687	32.343			
+20			34.472	0.5361	30.99
	8.174	66.815			
+40			38.245	0.5946	28.74
	10.249	105.06			
+60			32.74	0.5091	45.29
	11.738	137.80			
+80			45.80	0.7121	18.19
	13.55	183.60			
1 +00			25.05	0.3895	53.05
	14.421	208.65			
+20			31.75	0.4937	46.73
	15.505	240.40			
+40			38.00	0.5908	36.92
	16.687	278.40			
+60			40.90	0.6359	35.41
	17.868	319.30			
1 +80					

UNIVERSITY OF WISCONSIN.



COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 14 Car No. 54

Time - 1:50 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
–	8.816	77.72			
+20			45.37	0.7054	14.16
	11.093	123.09			
+40			46.56	0.724	15.80
	13.025	169.65			
+60			42.15	0.6554	30.66
	14.525	211.80			
+80			45.00	0.6996	19.44
	16.024	256.80			
1 +00			46.18	0.7181	20.19
	17.407	302.98			
+20			53.72	0.8352	12.58
	18.868	356.70			
+40			35.15	0.5466	42.34
	19.795	391.85			
+60			21.43	0.3334	65.66
–	21.03	412.28			
1 +80					

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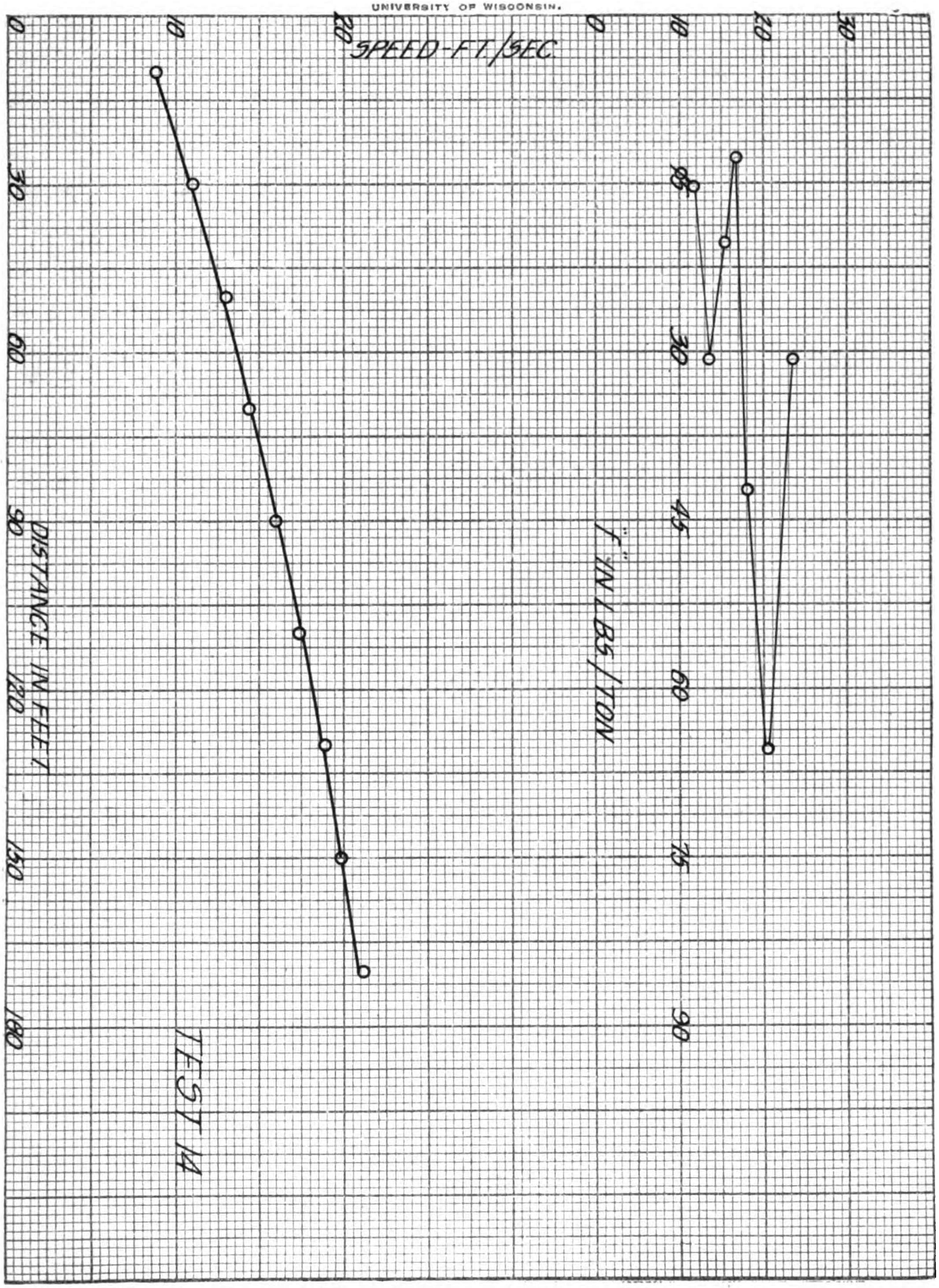

COLLEGE OF MECHANICS AND ENGINEERING.

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Test No. 13   Car No. 43

Time - 1:40 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	8.174	66.815			
+20			33.805	0.526	32.10
	10.35	100.62			
+40			54.78	0.8505	3.15
	12.463	155.40			
+60			38.60	0.6000	36.20
	13.92	194.00			
+80			54.50	0.8475	4.65
	15.75	248.50			
1 +00			29.90	0.426	45.50
	16.687	278.40			
+ 20					
	No record.				
+40					
	"	"			
+60					
	"	"			
+80					

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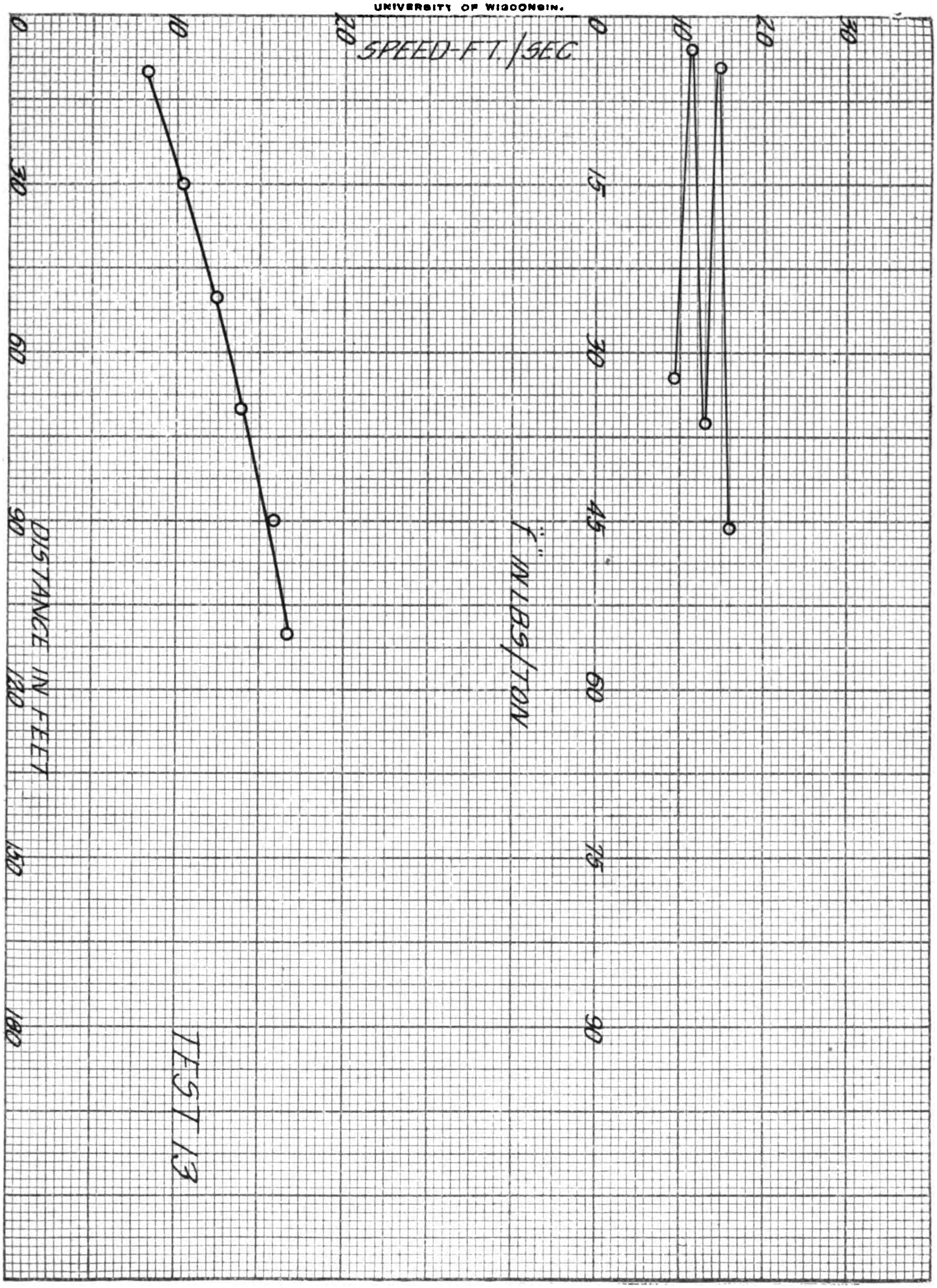

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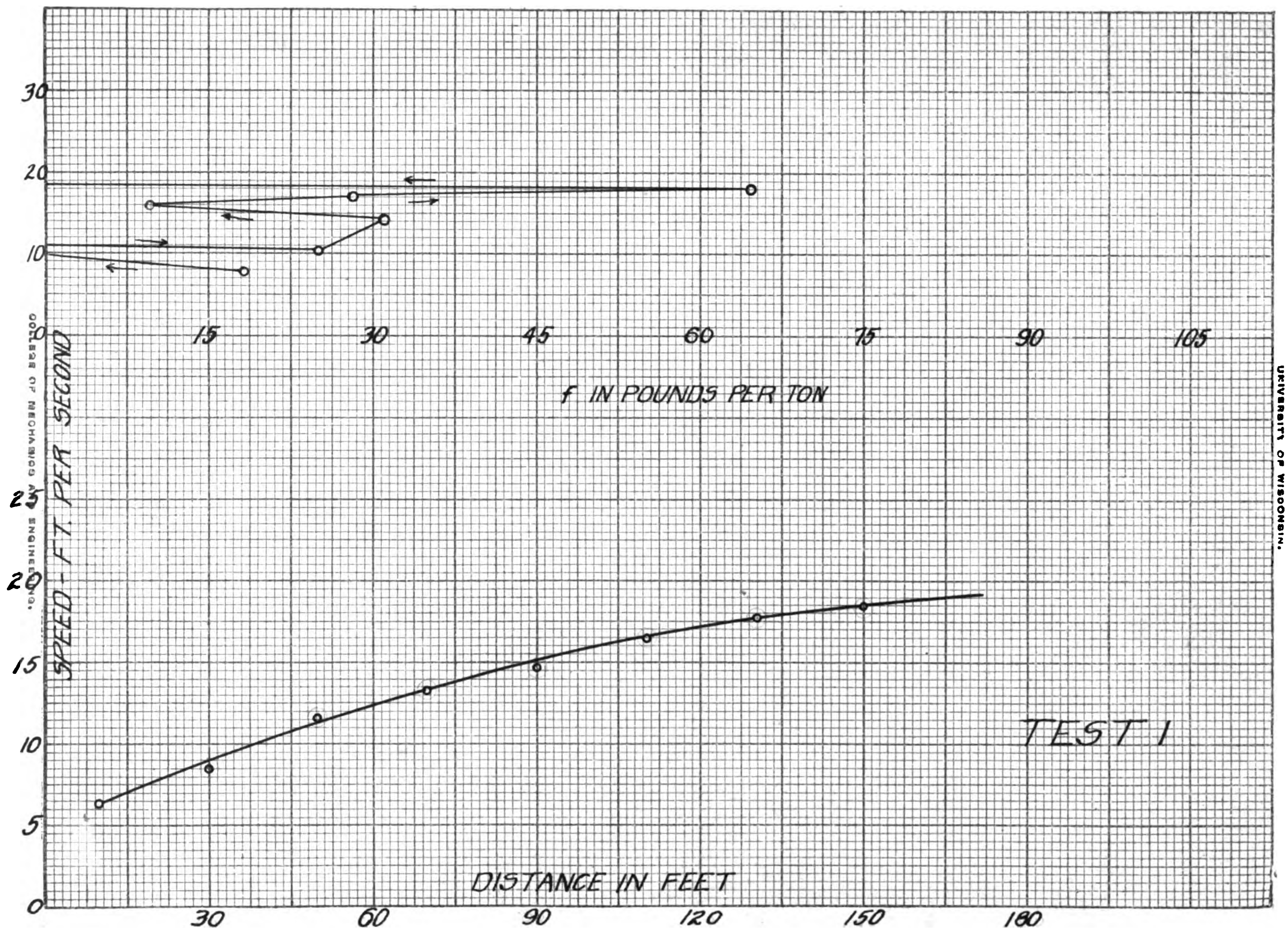
Test No. 1 Car No. 46

Time - 9:37 a. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	6.309	39.81			
+20			42.17	0.6557	19.13
	8.484	71.98			
+40			60.95	0.9477	6.57
	11.53	132.93			
+60			45.82	0.7124	24.96
	11.37	178.75			
+80			37.61	0.5847	30.93
	14.73	216.96			
1+00			52.97	0.8235	9.65
	16.41	269.93			
+20			43.72	0.6797	28.13
	17.71	313.65			
+40			20.15	0.3133	64.67
	18.27	333.80			
+60			69.80	1.085	9.5
	20.09	403.60			
+80					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COLLEGE OF MECHANICS AND ENGINEERING.
TEST I
SPEED - FT. PER SECOND
f IN POUNDS PER TON
DISTANCE IN FEET
0
15
30
45
60
75
90
105
10
20
30
5
10
15
20
25
30
60
90
120
150
180

Test No. 2 Car No.

Time - 9:47 a. m.

Station	Vol. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.344	53.95			
+20			42.17	0.6557	19.13
	9.802	92.16			
+40			45.88	0.7133	16.87
	11.874	141.00			
+60			37.75	0.5869	37.51
	13.37	178.75			
+80			17.80	0.2767	61.73
	14.02	196.55			
1+00			23.96	0.3225	54.75
	14.85	220.51			
+20			20.69	0.3217	63.95
	15.53	241.18			
+40			24.20	0.3762	58.38
	16.283	265.38			
+60			22.52	0.3501	63.99
	16.968	287.90			
+80					

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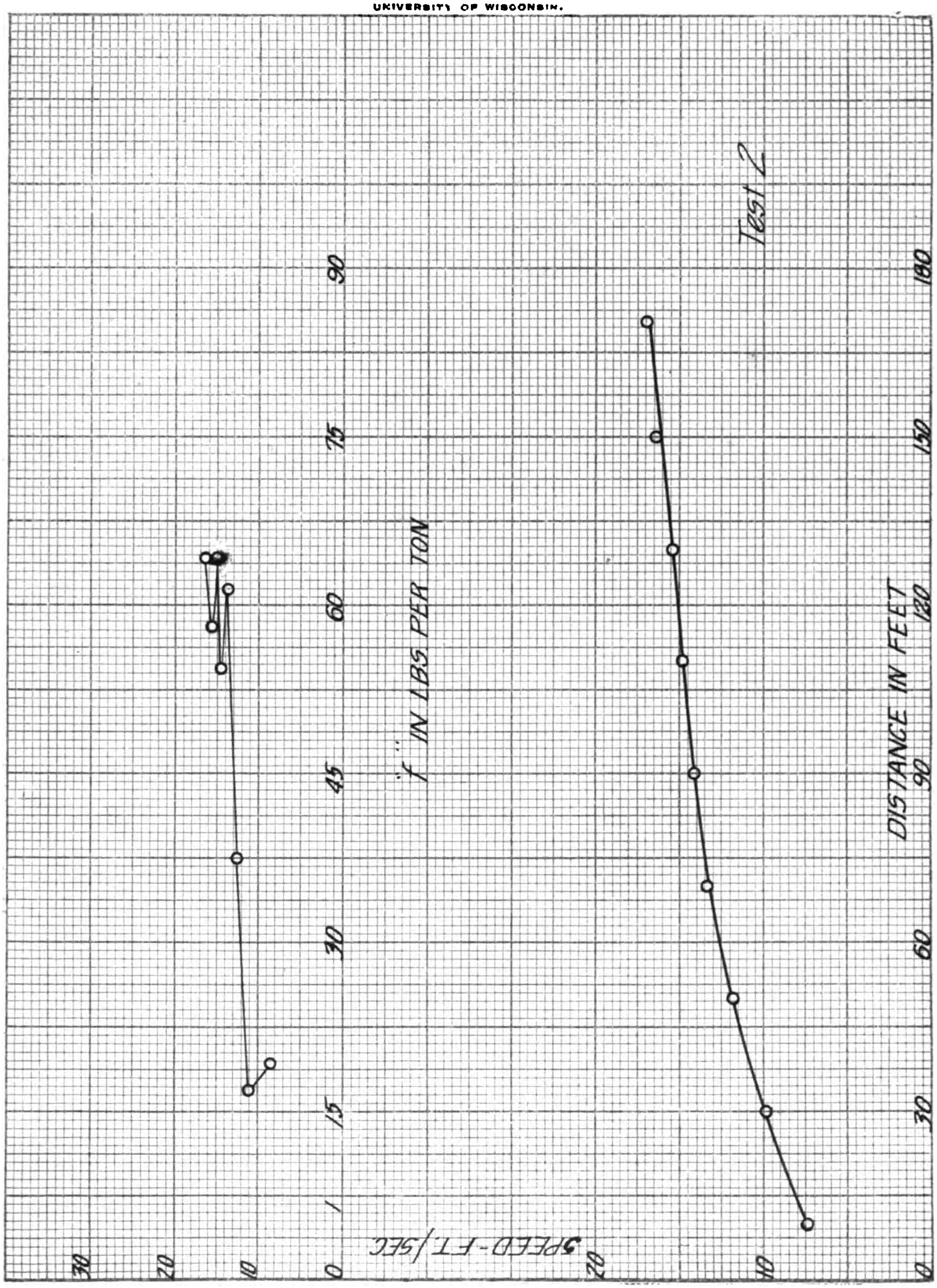

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Test No. 3 Car No. 47

Time - 9:54 a. m.

Station	Vol. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.256	52.65			
+20			42.53	0.6612	18.58
	9.756	95.18			
+40			42.62	0.6626	21.94
	11.738	137.80			
+60			48.30	0.7509	21.11
	13.642	186.10			
+80			38.70	0.6016	29.24
	14.925	224.80			
1+00			51.58	0.8079	11.21
	16.618	276.38			
+20			42.92	0.6673	29.37
	17.868	319.30			
+40			43.45	0.6756	28.44
	19.045	362.75			
+60			36.85	0.5730	31.70
	19.99	399.60			
+80					

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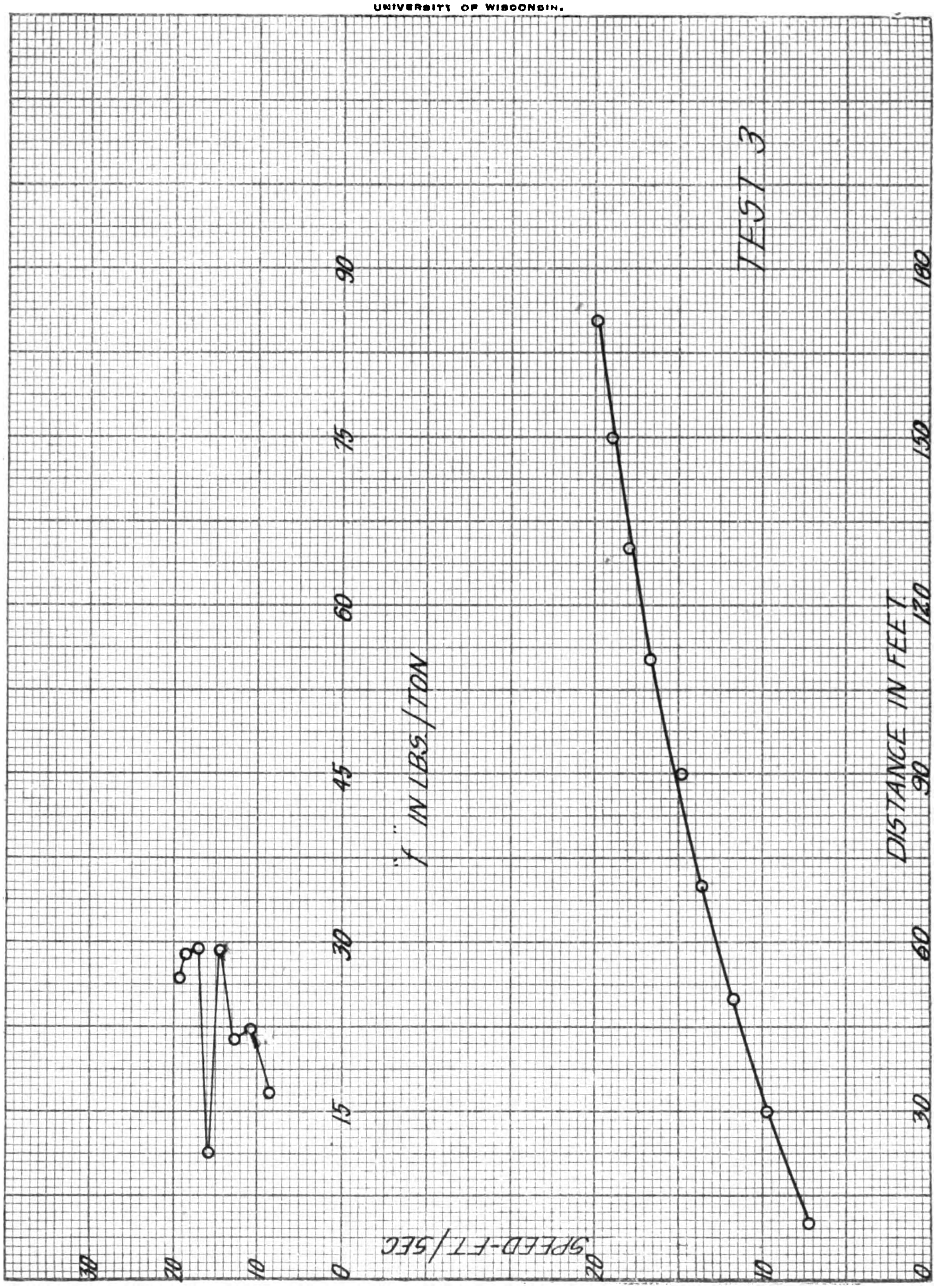
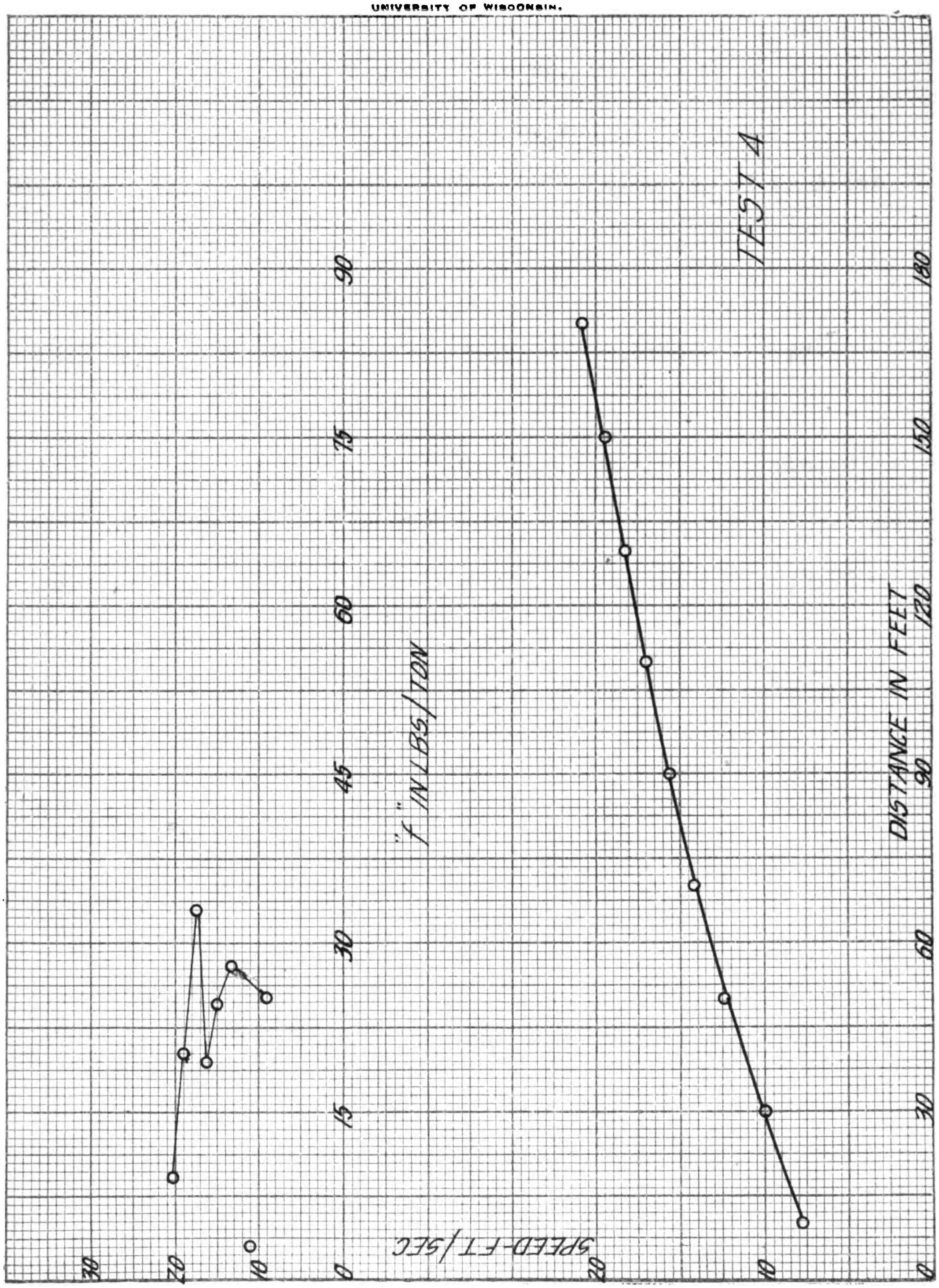


COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 4 Car No. 46

Time - 11:12 a.m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.886	62.19			
+20			38.14	0.5972	24.98
	10.03	100.60			
+40			54.80	0.852	3.00
	12.463	155.40			
+60			43.98	0.6838	27.82
	14.12	199.38			
+80			41.80	0.6499	24.41
	15.53	241.18			
1 +00			46.72	0.7264	19.36
	16.968	287.90			
+20			40.39	0.6280	33.30
	18.182	328.29			
+40			48.56	0.7550	20.50
	19.413	376.85			
+60			57.85	0.8994	9.06
	20.815	434.70			
+80					


TEST 4
DISTANCE IN FEET
0
30
60
90
120
150
180
"F" IN LBS/TON
0
15
30
45
60
75
90
SPEED-FT/SEC
30
20
10
0
20
10
0

Test No. 5 Car No. 52

Time - 11:25 a. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.885	62.19			
+20			39.71	0.6174	22.96
	10.095	101.90			
+40			46.05	0.716	16.60
	12.163	147.95			
+60			44.78	0.7118	25.02
	13.828	192.73			
+80			41.17	0.6401	25.39
	15.295	233.90			
1 +00			39.90	0.6203	29.97
	16.55	273.80			
+20			45.50	0.7074	25.36
	17.868	319.30			
+40			37.40	0.5816	37.85
	18.868	356.70			
+60			59.30	0.9220	6.80
	20.395	416.00			
1 +80					

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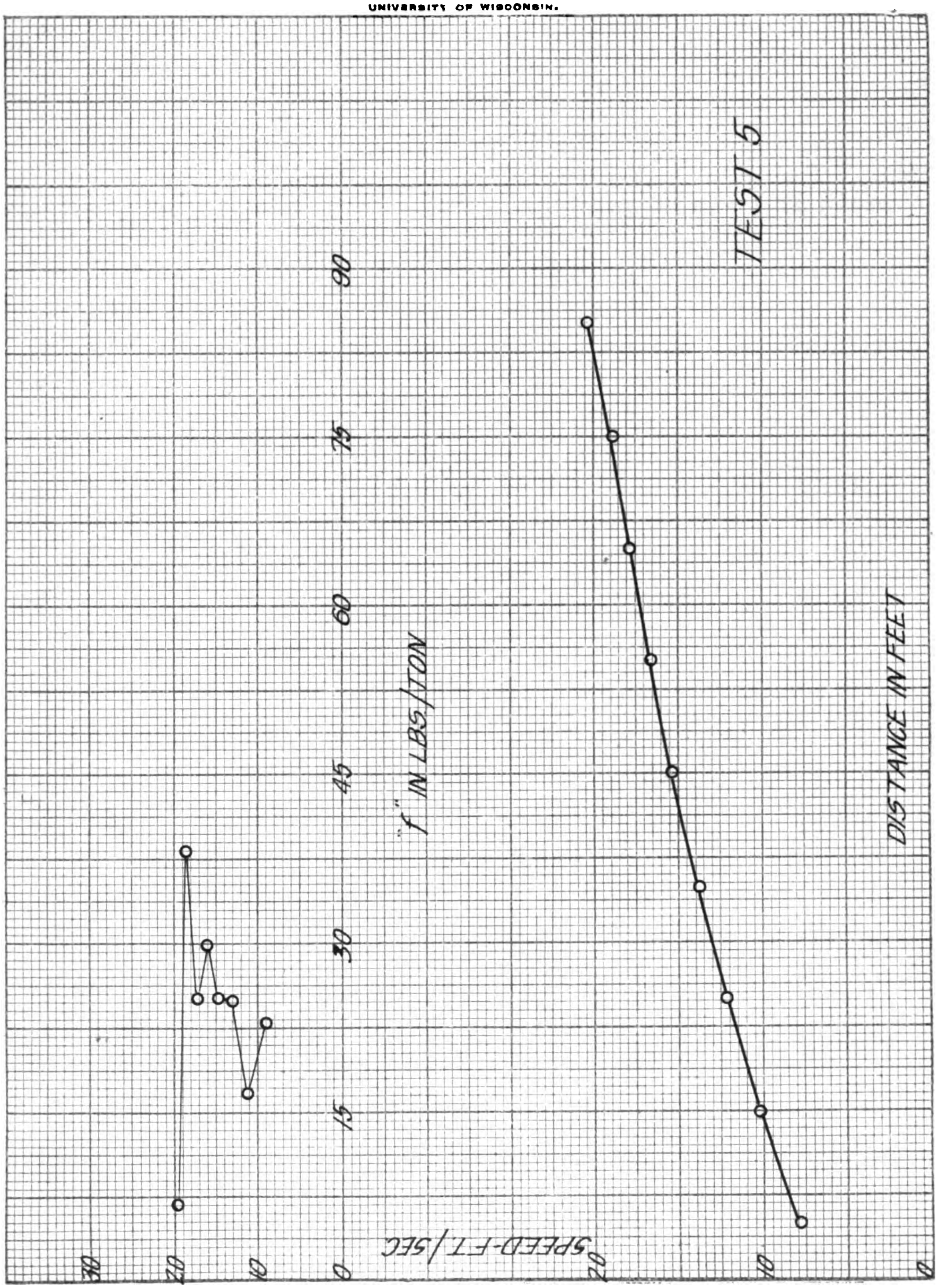

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 6 Car No. 47

Time - 11:35 a.m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_2^1$	$h_2 - h_1$	f in #/ton
0					
	8.174	66.815			
+20			41.485	0.6451	20.19
	10.408	108.30			
+40			43.30	0.6732	30.88
	12.312	151.60			
+60			43.65	0.6787	28.33
	13.973	195.25			
+80			39.85	0.6196	27.44
	15.352	235.10			
1+00			43.30	0.6732	24.68
	16.687	278.40			
+20			43.78	0.6808	28.02
	17.948	322.18			
+40			40.57	0.6308	32.92
	19.045	362.75			
+60			61.85	0.9615	2.85
	20.602	424.50			
+80					

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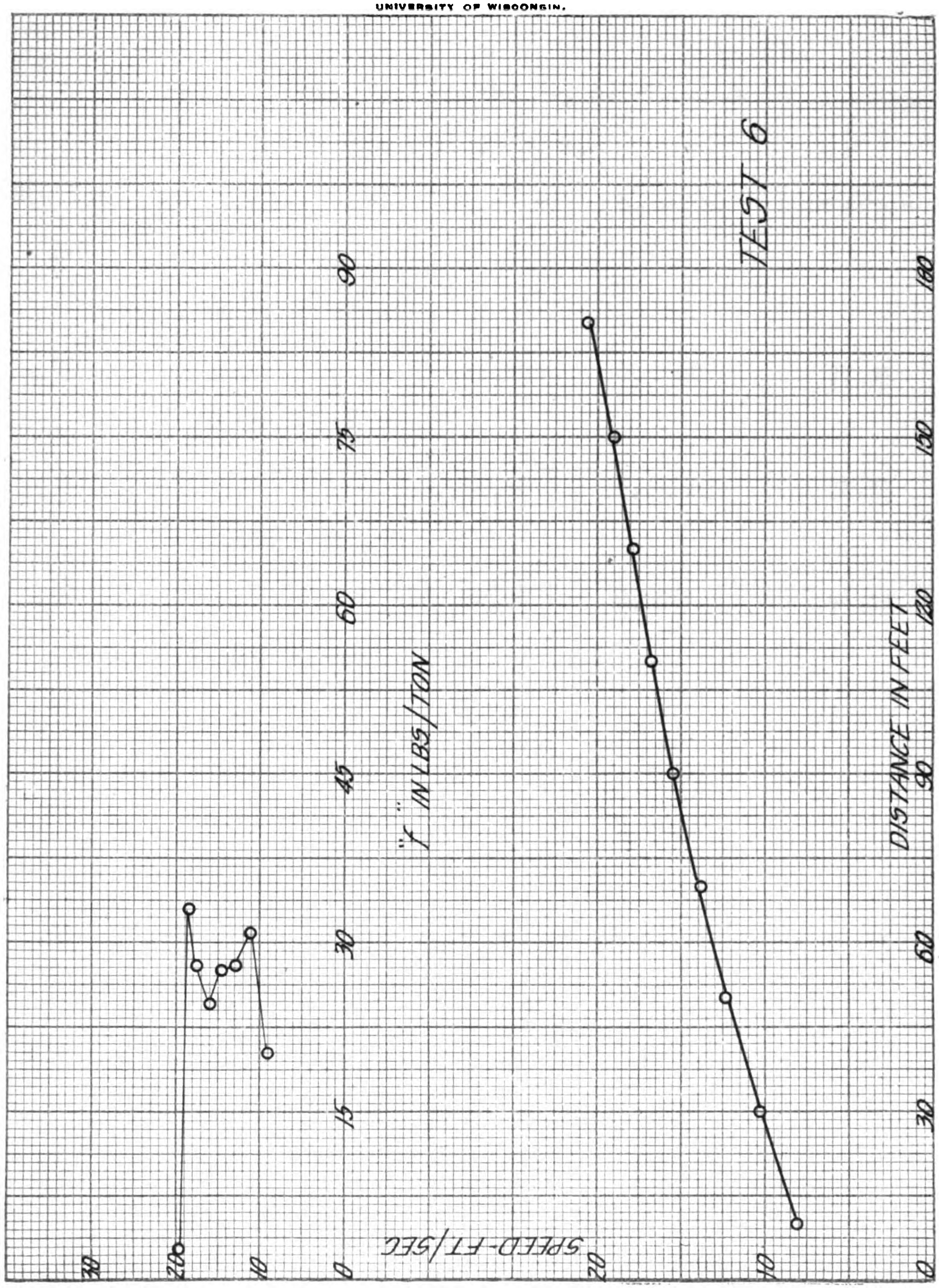

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 7 Car No. 43

Time - 11:54 a. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.302	53.345			
+20			36.925	0.5742	37.28
	9.501	90.27			
+40			41.63	0.6473	23.47
	11.485	131.90			
+60			32.20	0.5007	46.13
	12.81	164.10			
+80			40.98	0.6372	25.68
	14.32	205.08			
1 +00			35.32	0.5492	37.08
	15.505	240.40			
+20			37.40	0.5816	37.94
	16.668	277.80			
+40			41.50	0.6453	31.47
	17.868	319.30			
+60			50.48	0.7840	20.60
	19.229	369.78			
+80					

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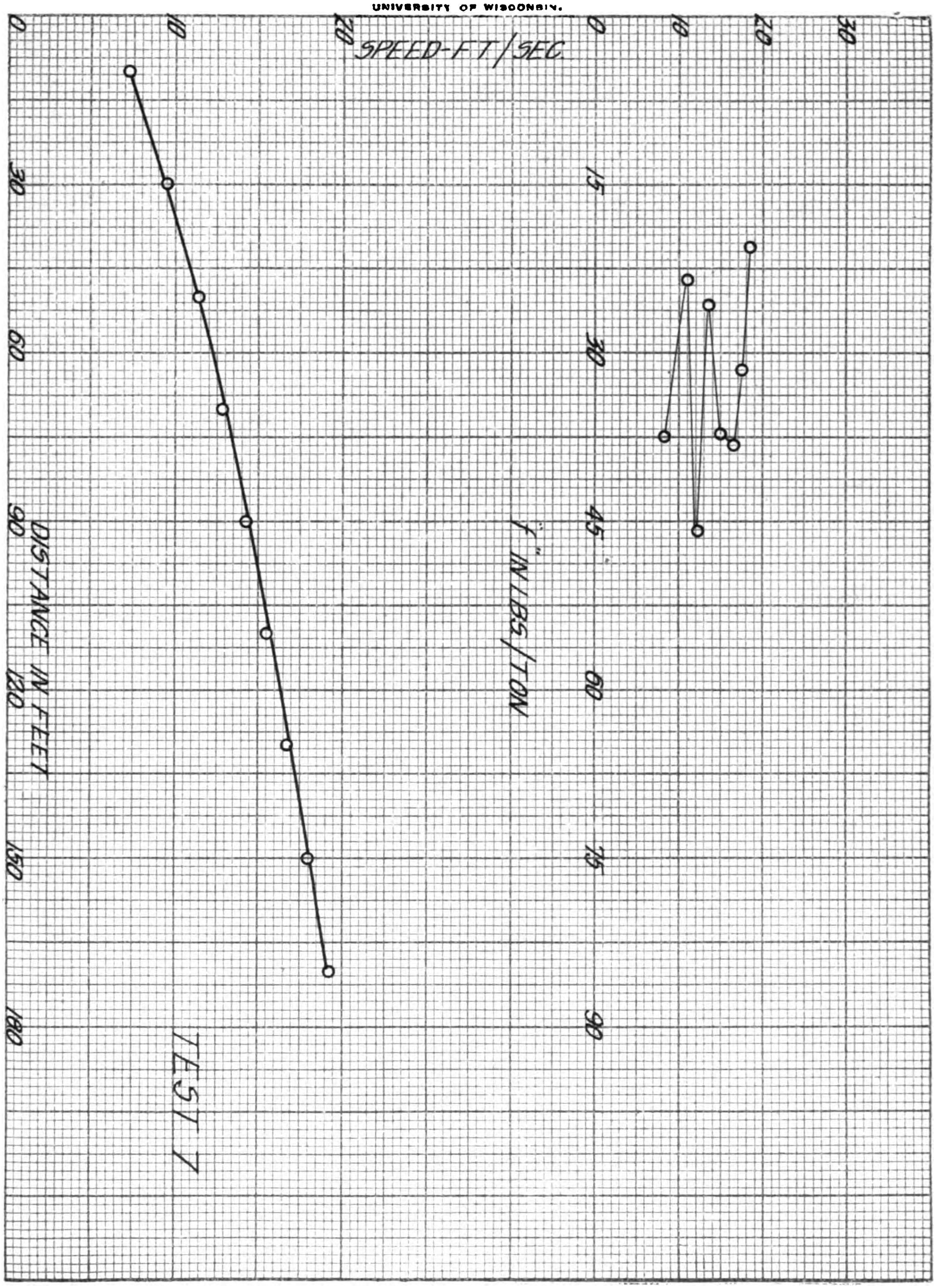

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 8   Car No. 54

Time - 12;07 p.m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	9.347	87.36			
+20			39.87	0.6199	22.71
	11.280	127.23			
+40			46.90	0.7293	15.27
	13.196	174.13			
+60			42.83	0.6659	29.61
	14.73	216.96			
+80			48.42	0.7528	14.12
	16.283	265.38			
1+00			42.91	0.6672	25.28
	17.558	308.29			
+20			20.00	0.3109	65.01
	18.182	328.29			
+40			55.91	0.8692	9.08
	19.602	384.20			
+60					

Paper running too slow.

1+80

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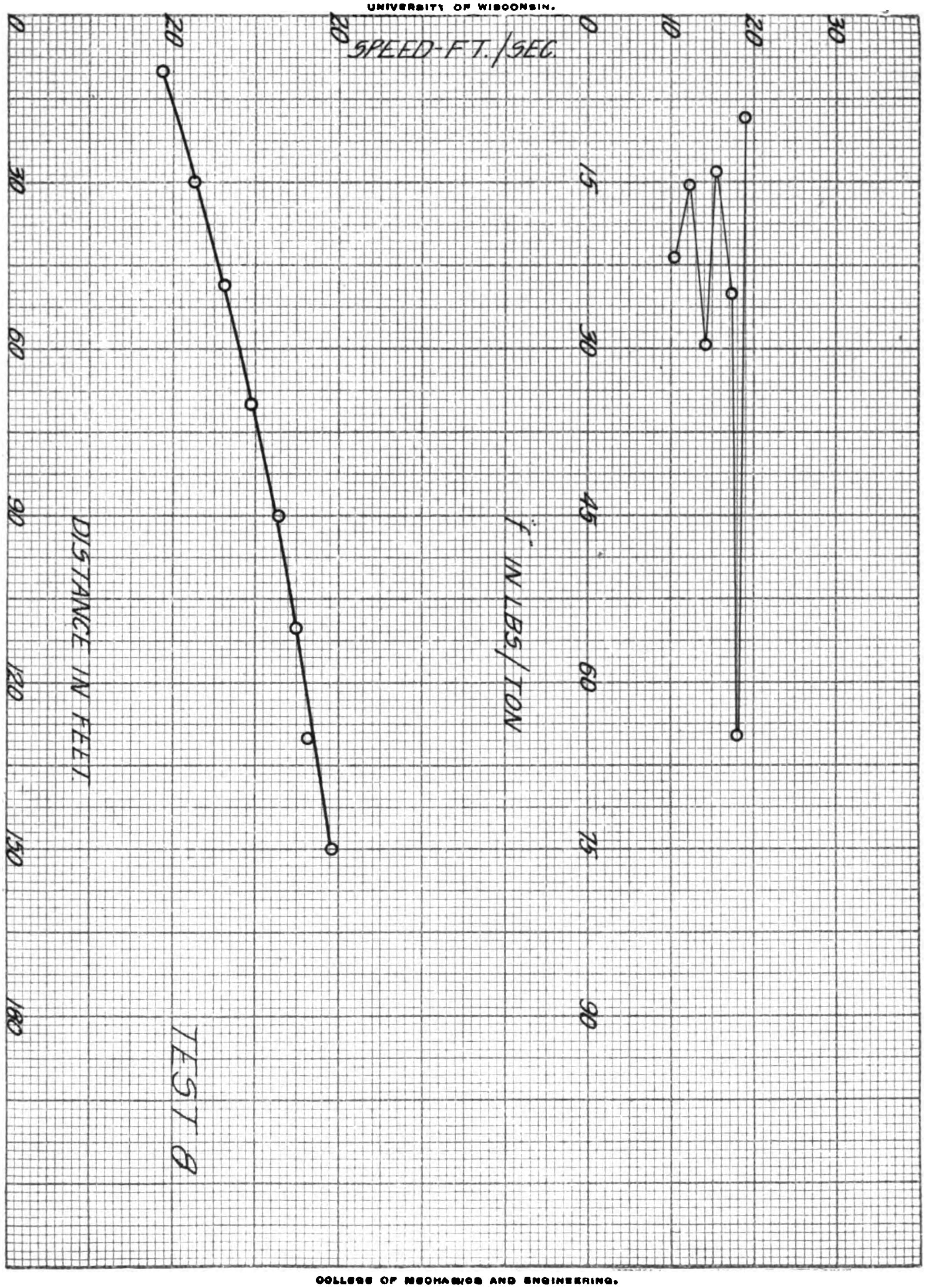

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 9 Car No. 46

Time - 12:22 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	5.768	33.27			
+20			33.545	0.5216	32.54
	8.174	66.815			
+40			36.115	0.5616	32.04
	10.145	102.93			
+60			34.87	0.5422	41.98
	11.738	137.80			
+80			23.47	0.3649	52.91
	12.698	161.27			
1 +00			40.93	0.6364	28.36
	14.22	202.20			
+20			40.81	0.6345	32.65
	15.59	243.01			
+40			35.39	0.5503	40.97
	16.687	278.40			
+60			35.25	0.5481	44.19
	17.71	313.65			
1 +80					

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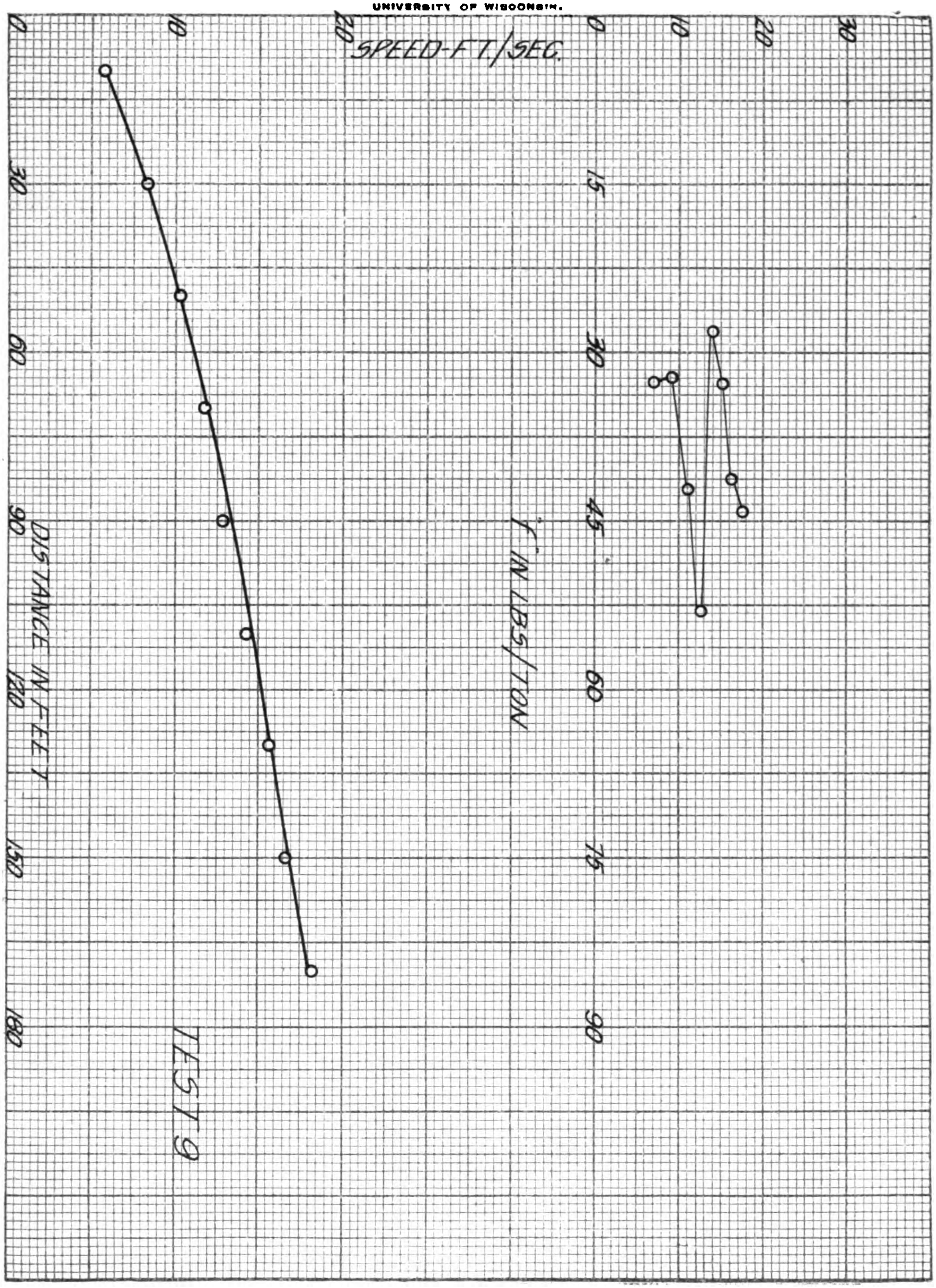

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 10 Car No. 52

Time - 1:05 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	6.707	44.97			
+20			28.22	0.6992	14.78
	8.555	73.19			
+40			66.75	0.1037	67.83
	8.934	79.815			
+60			0.695	0.01041	95.159
	8.973	80.51			
+80			0	0	89.40
	8.973	80.51			
1 + 00			10.20	0.1586	76.14
	9.524	90.71			
+20			21.19	0.3295	65.15
	10.626	112.90			
+40			15.72	0.2444	71.56
	11.342	128.62			
+60			34.69	0.5394	45.06
	12.779	163.31			
1 + 80					

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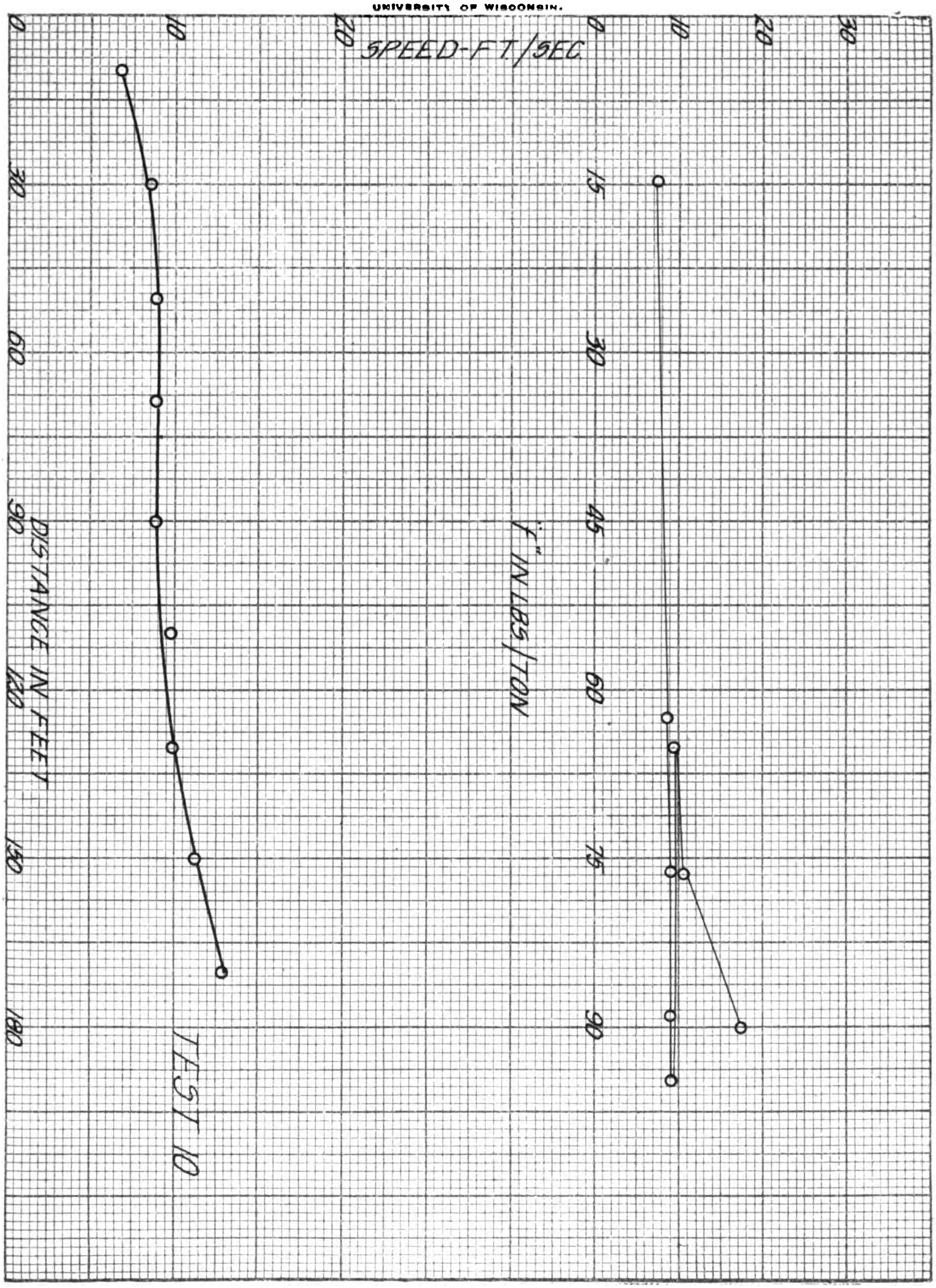

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 11 Car No. 50

Time - 1:20 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	7.677	58.94			
+20			46.12	0.7171	12.99
	10.249	105.06			
+40			48.34	0.7516	13.04
	12.385	153.40			
+60			45.98	0.7149	24.71
	14.12	199.38			
+80			41.80	0.650	24.40
	15.53	241.18			
1+00			46.72	0.7265	19.35
	16.968	287.90			
+20			40.39	0.628	33.30
	18.182	328.29			
+40			52.31	0.8135	14.65
	19.509	380.60			
+60			57.10	0.8878	10.22
	20.925	437.70			
1+80					

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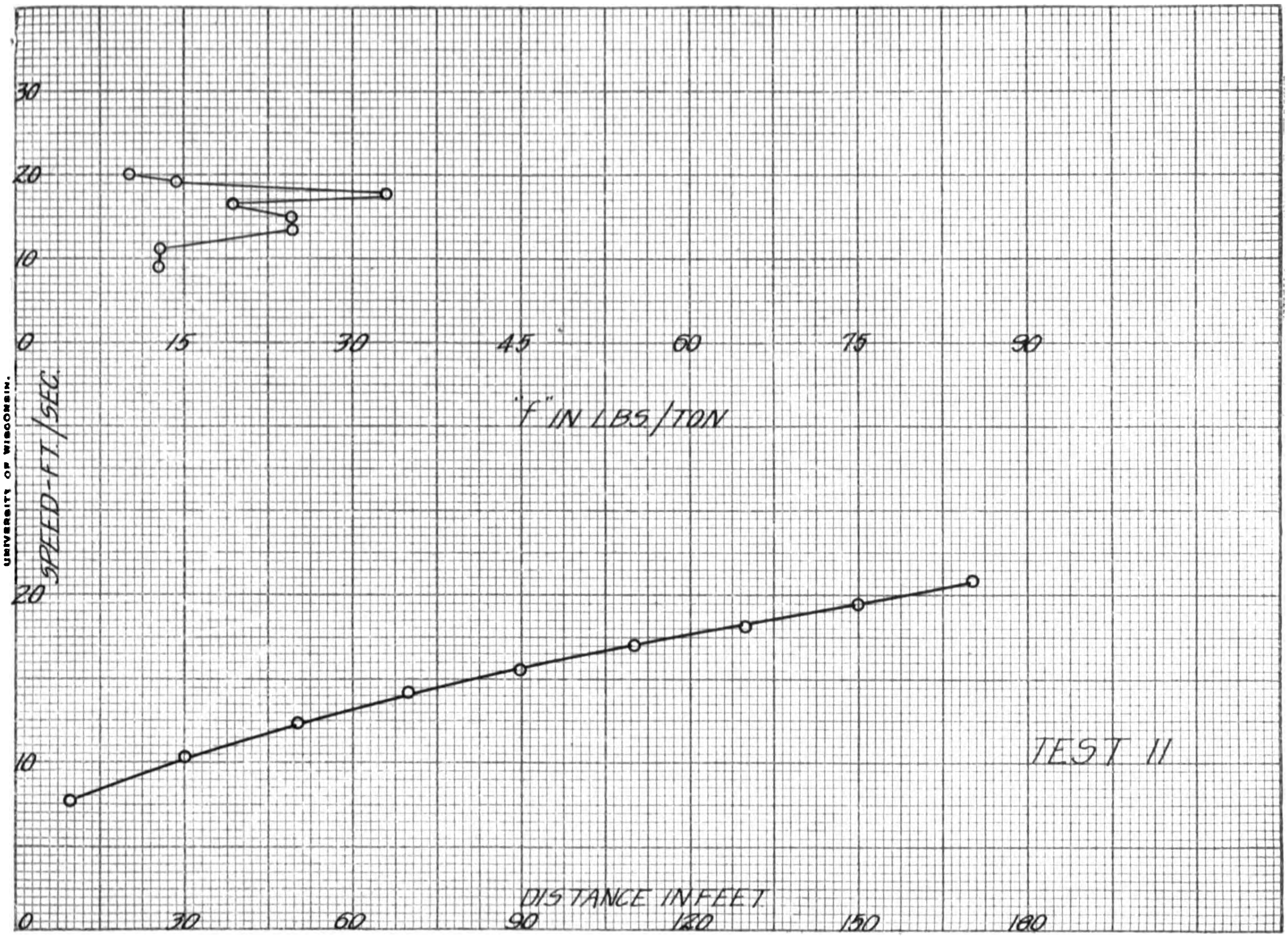

COLLEGE OF MECHANICS AND ENGINEERING.

Test No. 12 Car No. 51

Time - 1:29 p. m.

Station	Vel. ft/sec	v^2	$v_2^2 - v_1^2$	$h_2 - h_1$	f in #/ton
0					
	11.280	127.23			
+20			45.79	0.712	13.50
	13.153	173.02			
+40			50.66	0.7876	9.44
	14.955	223.68			
+60			37.30	0.580	38.20
	16.153	260.98			
+80			52.67	0.8189	7.51
	17.71	313.65			
1 +00			52.70	0.8194	10.06
	19.14	366.35			
+20			49.65	0.772	18.9
	20.395	416.00			
+40			40.40	0.6281	33.19
	21.363	456.40			
+60			63.85	0.9927	.27
	22.815	520.25			
1 +80					

Note:- The axles of this car rest on roller bearings.

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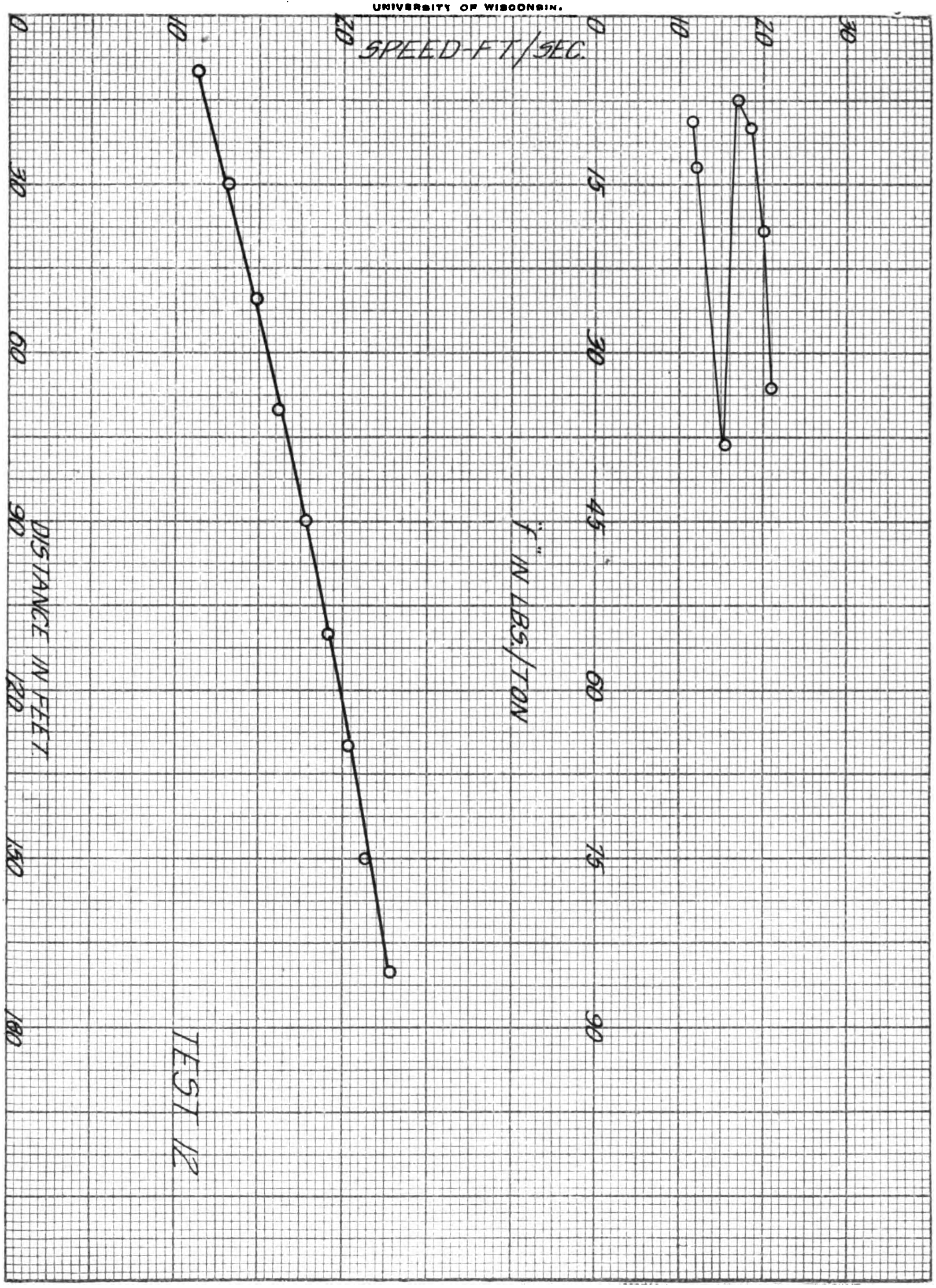


COLLEGE OF MECHANICS AND ENGINEERING.

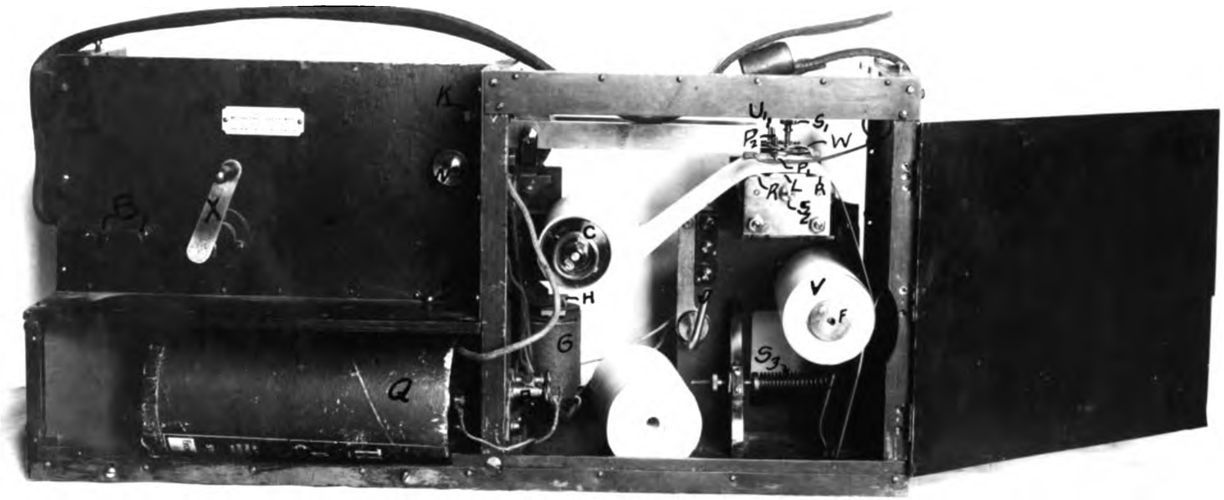


PLATE I.- FRONT VIEW OF CHRONOGRAPH

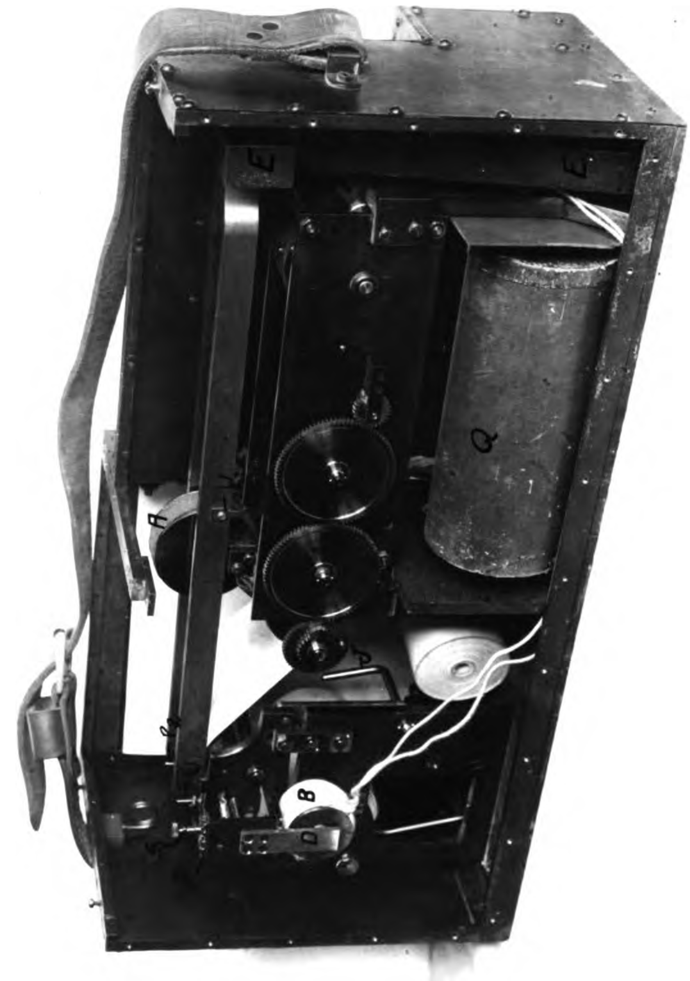


PLATE 2 - REAR VIEW OF CHRONOGRAPH

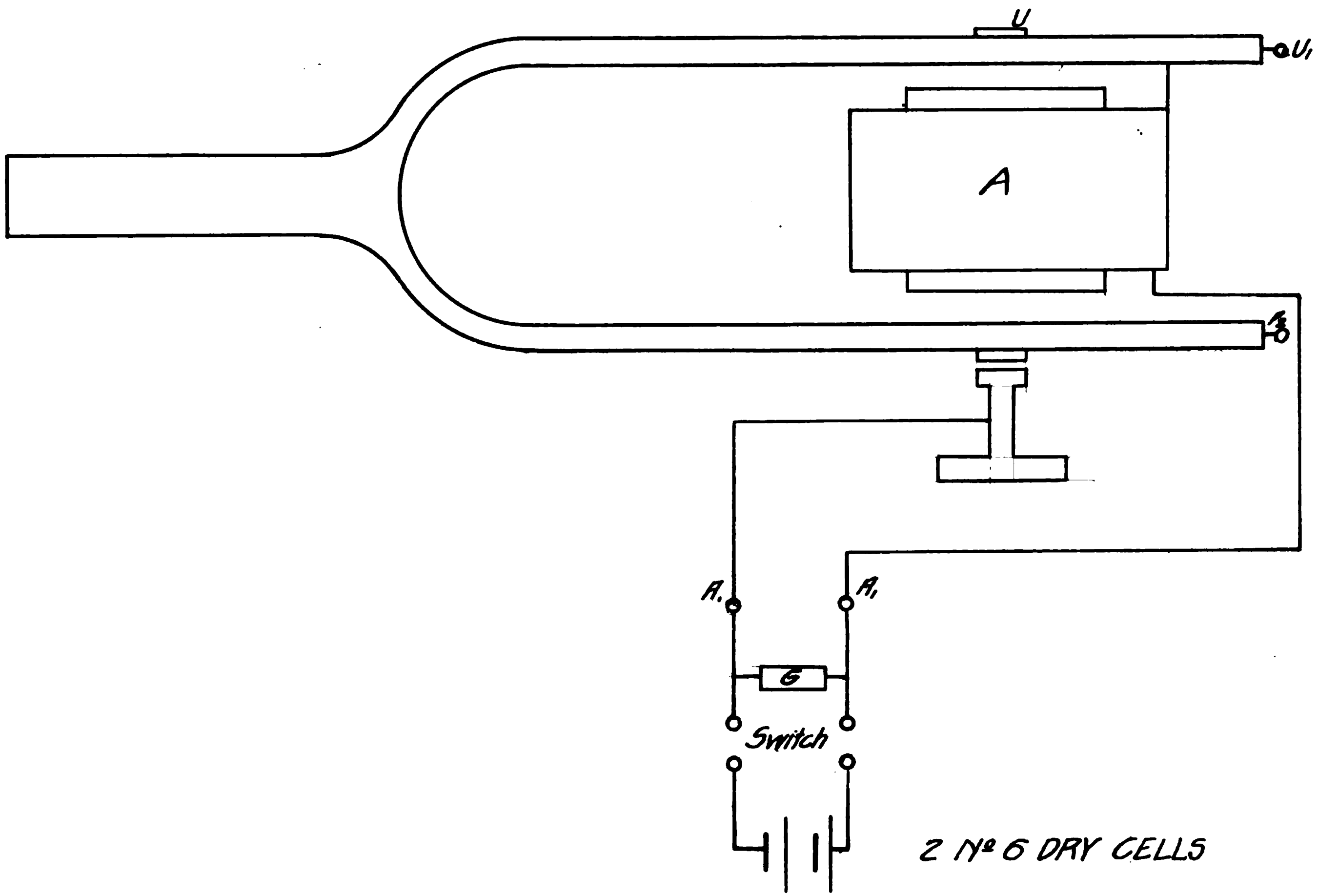
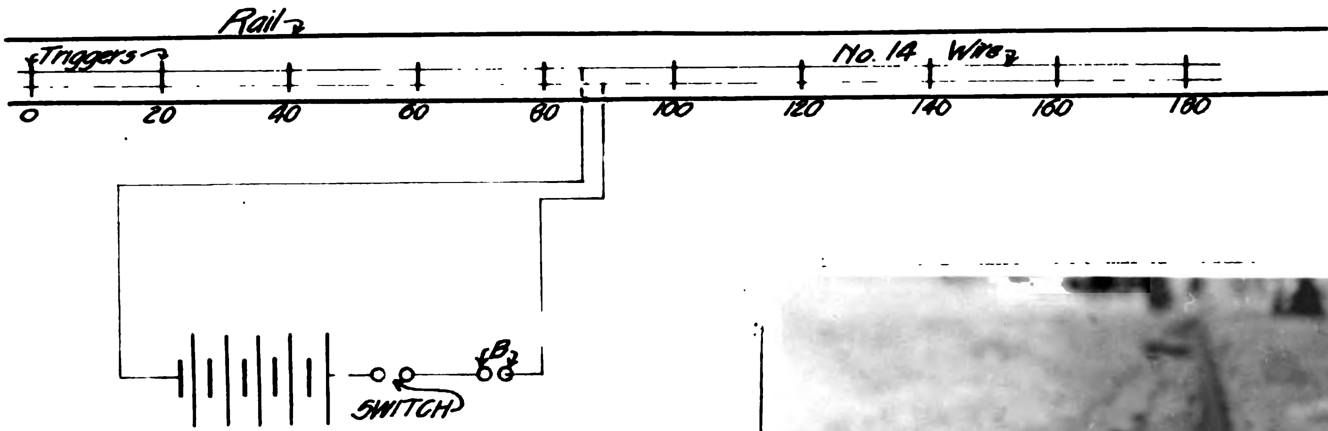
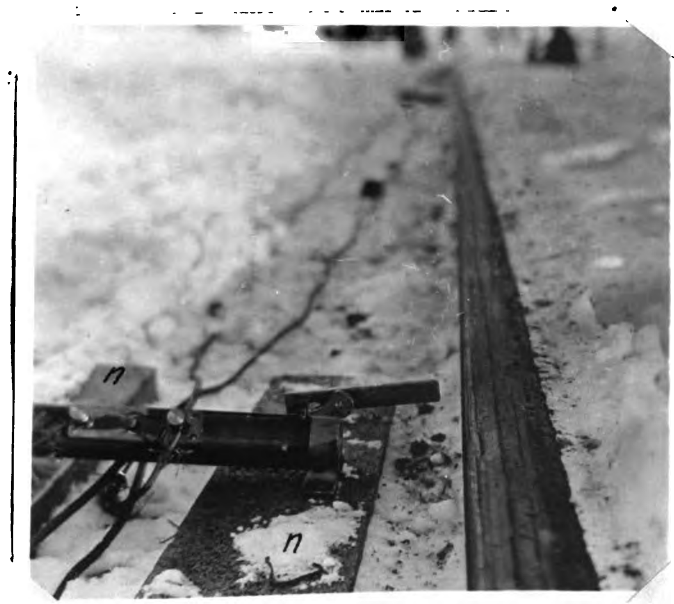


PLATE 3 - CONNECTIONS FOR TUNING FORK & CLOCKWORK CIRCUITS.



5 No 8 DRY CELLS



TRIGGER IN PLACE

PLATE 4 - TRACK LAYOUT

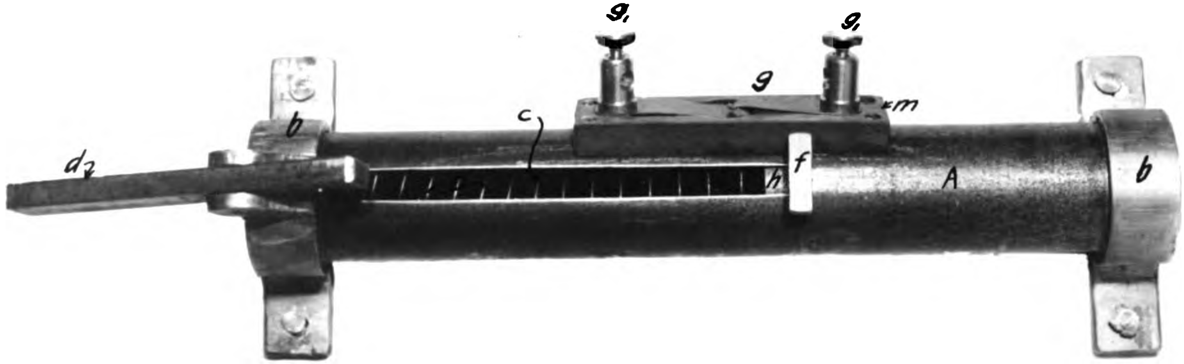


PLATE 5-TOP VIEW OF TRIGGER

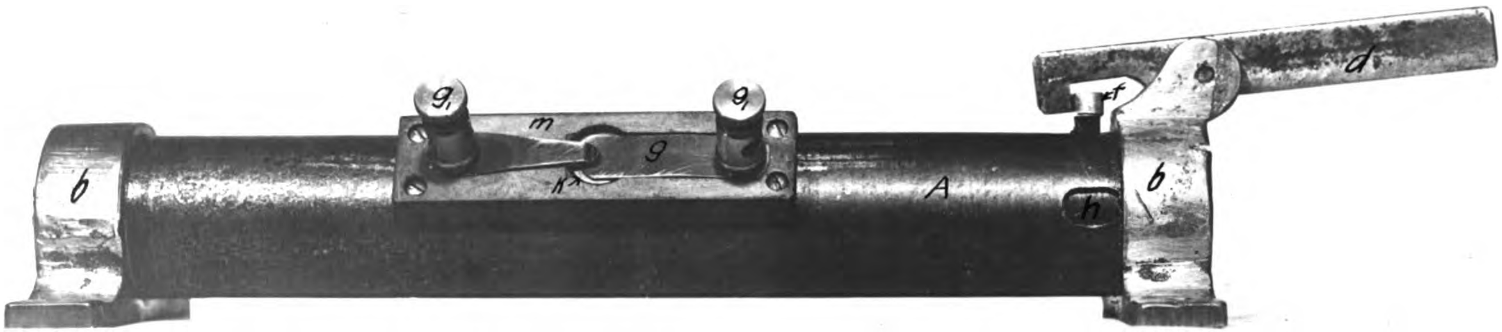
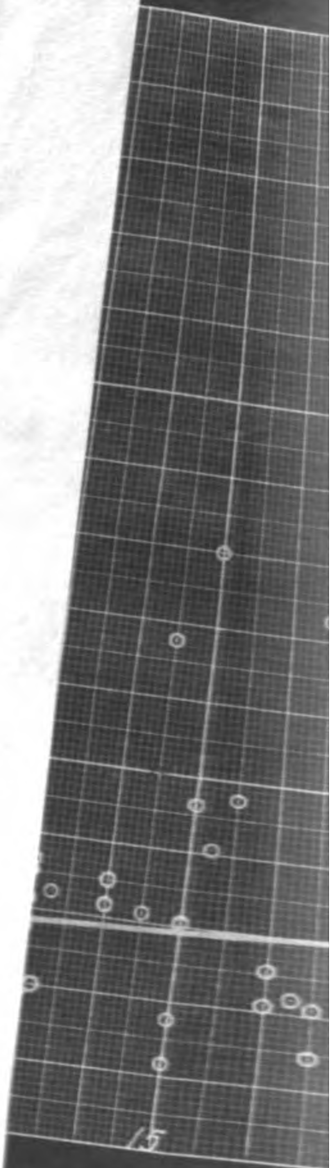


PLATE 6 - SIDE VIEW OF TRIGGER.

PLATE 7- VIEW OF TRACK

From
Test No. 15
Car No 45
Jan. 23, 1912 2:05 P.M.

PLATE 8 - SAMPLE RECORDS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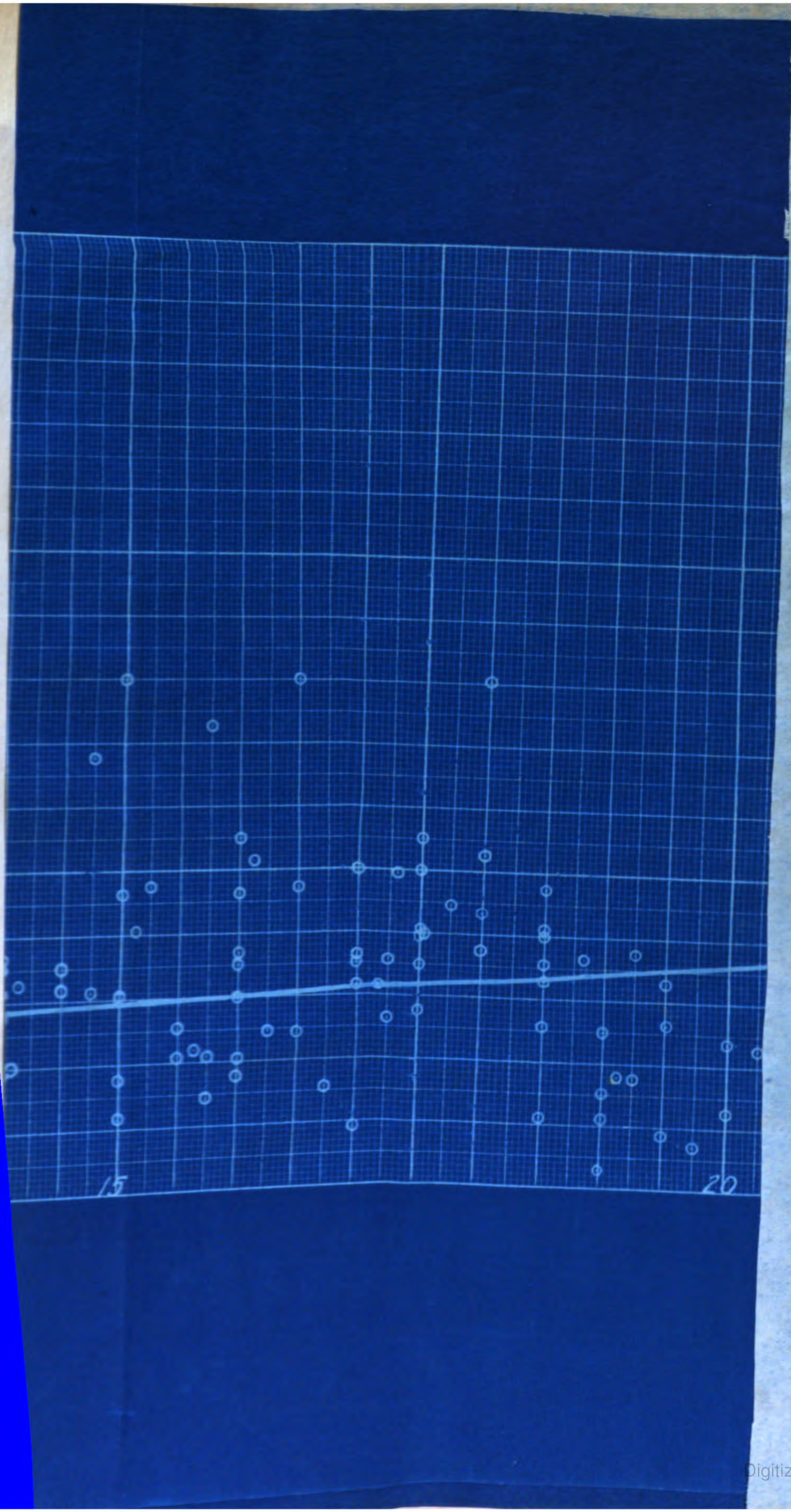
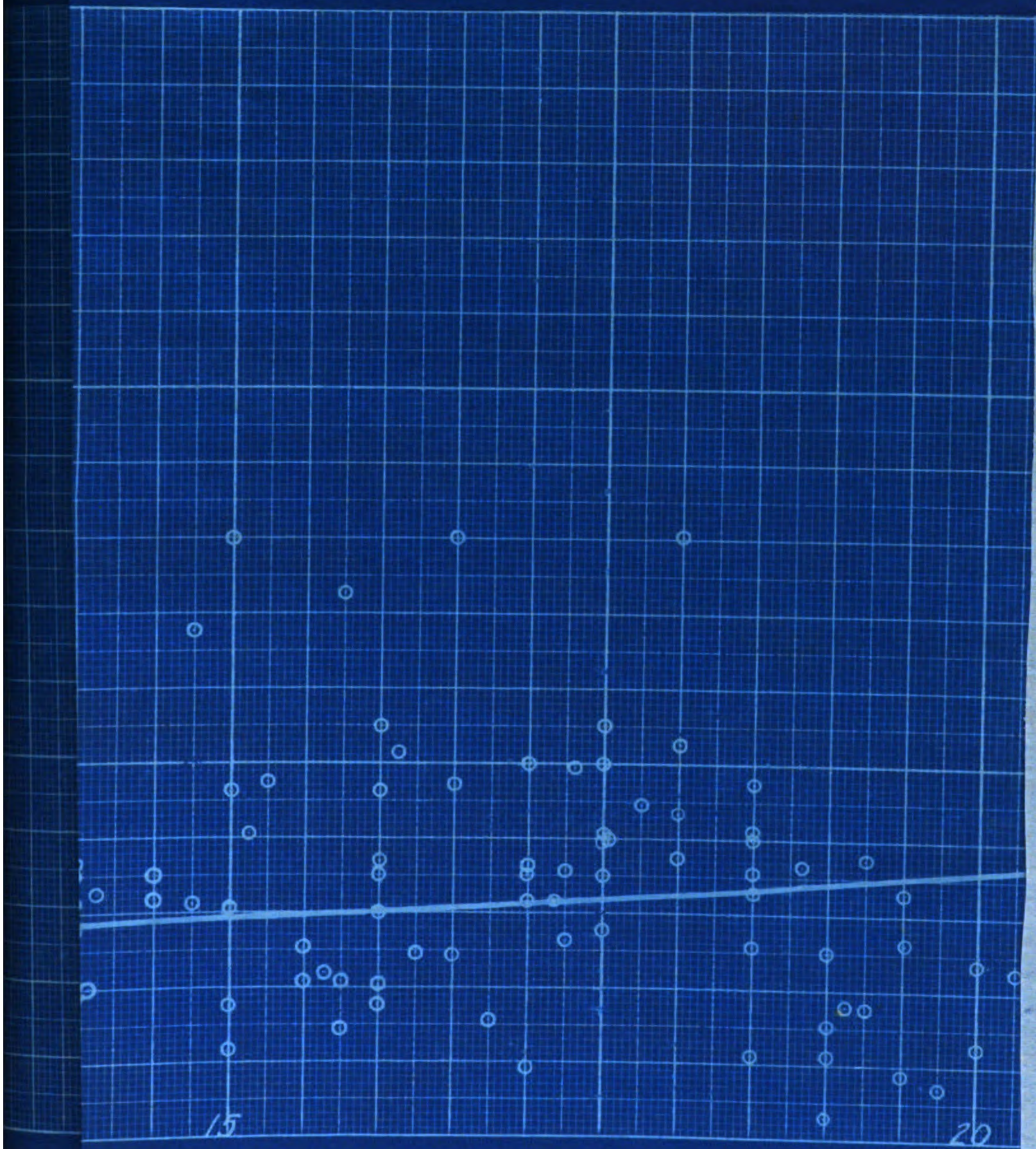

15
20


15
20

CONCLUSIONS

Car resistance in general is made up of several parts or components whose exact amount is difficult to determine. The conditions which affect these ~~these~~ elements include temperature, kind of lubrication, condition of the track, the speed and weight of car, and the state of the weather as to wind, etc. Temperature and the lubricants work in close accord. The condition of the track and the speed and weight of the car enter into the conditions which affect the total resistance to a very great extent. In the case of a rough roadbed the resistance at any one point is found to vary considerably. For a given speed the resistance in pounds ~~power~~ per ton has been found by experiments to be greater the lower the weight of the car. These remarks apply to train resistance tests in general.

In the tests which are included in this thesis the writer was not able to actually verify all the above statements, partly because of adverse weather conditions. However, the accompanying diagram (Sheet No. 1) showing the relationship between the total resistance and the speed of the car indicates that for an increase in speed the resistance also increases.

On curve sheet No. 2 is plotted the relationship of the resistance to car weight at the three different speeds of 5, 10

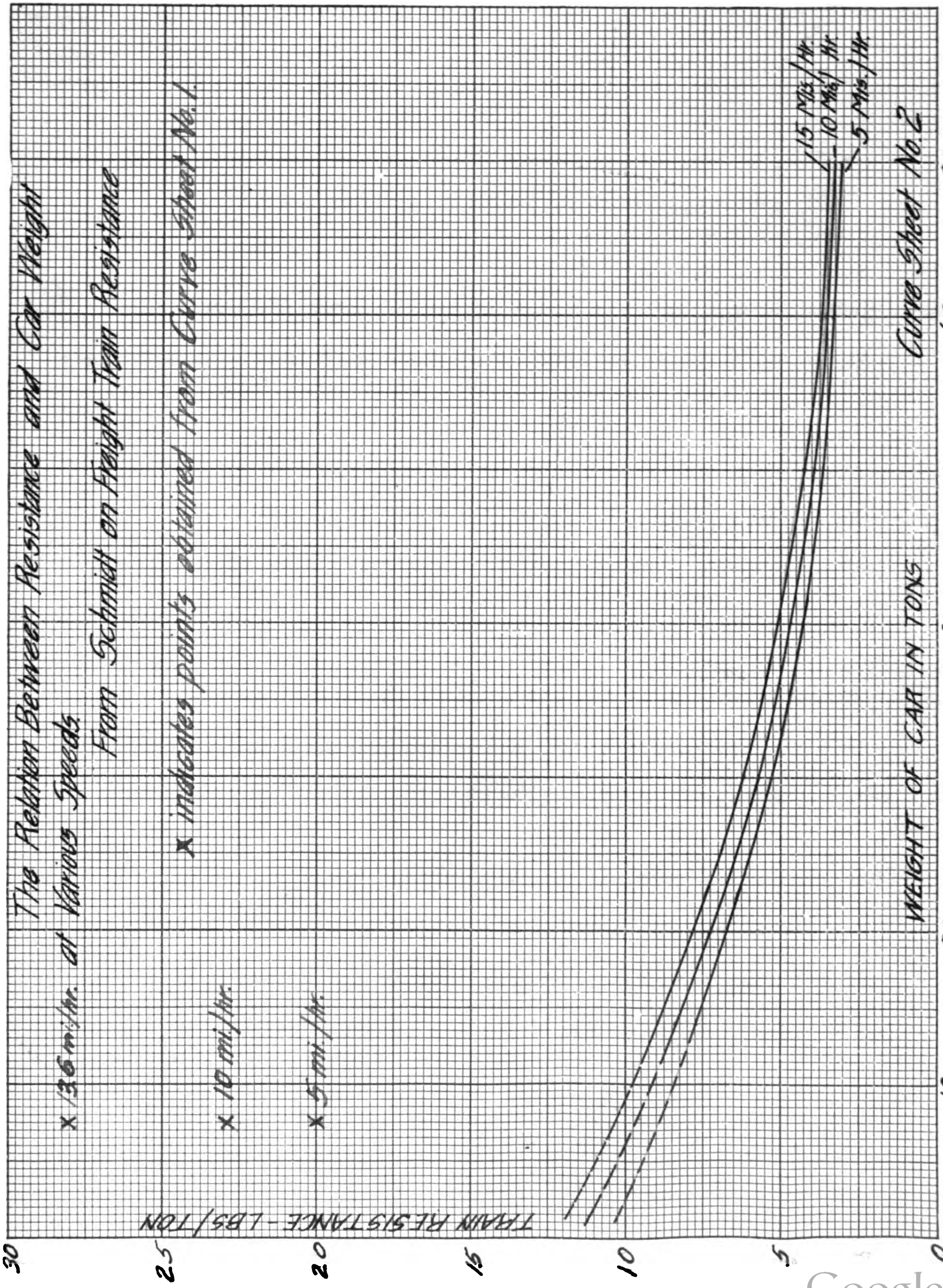
and 15 miles per hour as obtained from the bulletin entitled "Freight Train Resistance" by Professor E. C. Schmidt of the University of Illinois. The dotted lines indicate that the original curves have been extended in about the same general direction. The weight of the cars used in these tests is approximately seven and one-half tons. On the latter curve sheet the writer has plotted the values that he obtained with the seven and one-half ton car and at the speeds of 5, 10 and 13.6 miles per hour.

The radical difference in type of rolling stock of course prevents close comparisons, but it is noted that the values plotted from the present experiments lie in the general direction to be expected. In attempting to arrive at some reason for the exceptionally high values found in the present tests, the writer, having in mind the low temperature prevailing when the present tests were made, calls attention to the conclusions reached in the analysis of steam road tests made by Schmidt during cold weather.

Professor Schmidt says in his paper on "The effects of cold weather upon tonnage ratings" (See Official Proceedings of the Central Railway Club, Vol. 18, No. 1, January 1912) that it is in journal friction that we must seek the explanation of the effect which cold weather is known to produce upon train resistance. Figure 3 of the above mentioned paper is very similar

to any of the curves of the individual tests which are included in this thesis, in that there is such a wide variance of resistance for any speed. The writer quotes from Schmidt (page 81) the following sentence in regard to his figure 3: "If there is a definite relation between resistance and speed for this test, figure 3 certainly does not disclose it, and it would require considerable hardihood to try to draw a curve for the points there shown." The writer found this to be true in the case of the data of this thesis, and only after using an exaggerated scale for speed was a fairly good curve obtained. In the case which Professor Schmidt cites the temperatures varied thirty to forty-two degrees, Fahrenheit, while in the writer's case the temperature averaged about twenty-five degrees.

Until the journal friction has been thoroughly investigated in cold weather, definite conclusions cannot be reached, and the results of the present thesis are submitted as a progress study, in the hope that some aid may be afforded, at least in the development of a method of observation and investigation.


The Relation Between Resistance and Car Weight
at Various Speeds.
From Schmidt on Freight Train Resistance
x indicates points obtained from Curve Sheet No. 1.
x 36 mi/hr.
x 10 mi/hr.
x 5 mi/hr.
15 Mis./Hr.
10 Mis./Hr.
5 Mis./Hr.
Curve Sheet No. 2
WEIGHT OF CAR IN TONS
TRAIN RESISTANCE - LBS/TON
0
10
20
30
40
50
60
70
5
15
25

APPENDIX

Suggestions for Conducting Future Tests

From the small number of tests obtained the following suggestions in regard to conducting field tests stand out prominently:

1. The first wheel of the car should be brought as close as possible to the trigger at station zero before allowing the car to start drifting.

2. In the first twenty feet the writer would place a trigger at the following distances from station zero, in order to determine the resistance at starting: 0, 5, 10 and 20.

3. It is recommended that at the very low speeds the 1911 trigger (designed by Pflanz and Schwada) should be used. Thus the 1912 design can be used entirely at high speeds and the distance over which readings are taken can be lengthened.

APPROVED BY

W. D. Pence.

Professor of Railroad Engineering.